[redacted]

NASA CONTRACTOR REPORT

NASA CR-61074

CLASSIFICATION CHANGE
To UNCLASSIFIED
By authority of GDS-GP-4 ... 12/74
by L. Shirley ... Station, NASA
... Technical Information Facility

(NASA-CR-61074) LEM APPLICATION TO LUNAR SHELTERS AND MOBILE VEHICLES (Northrop Space Labs.) 253 p

N79-76133

Unclas
00/12 11022

[redacted]
(NASA CR OR TMX OR AD NUMBER)

(CODE)
3/
(CATEGORY)

LEM APPLICATION TO LUNAR SHELTERS AND MOBILE VEHICLES [U]

Prepared under Contract No. NAS8-11096 by

Jerome E. Ligocki
Glenn J. Youngblood

NORTHROP SPACE LABORATORIES
Space Systems Section
Apollo Extension System Studies

~~GROUP 4
Downgraded at 3 year intervals;
declassified after 12 years~~

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

[redacted]

SECURITY NOTE

This document contains information affecting the national defense of the United States within the meaning of the Espionage Law, Title 18, U.S.C., Section 793 and 794, as amended. The transmission or revelation of its contents in any manner to an unauthorized person is prohibited by law.

ABSTRACT

C65-8959

A study has been completed for the conversion of LEM to an extended stay lunar shelter and a mobile lunar vehicle. Minimum modification to existing LEM subsystems was a requirement for both conversions. The lunar stay-time was extended from four to fourteen days and a six month storage period requirement was added.

The results of the study indicate the LEM shelter conversion is feasible with minimum modification to LEM. However, the conversion of LEM to a mobile lunar vehicle is shown to require major modification to existing LEM subsystems.

Payload weight capability for the LEM Shelter was determined to be 3600 pounds. This weight may be allocated for supplemental mobility aids, such as the LSSM and/or the LFV, and scientific instrumentation. Recommendations are made for additional studies in particular areas for the LEM subsystem conversions required to facilitate their use in the LEM Shelter.

~~CONFIDENTIAL~~

CR-61074

APOLLO EXTENSION SYSTEM STUDIES
REPORT ON

LEM APPLICATION TO LUNAR SHELTERS AND MOBILE VEHICLES [U]

By

Jerome E. Ligocki
Glenn J. Youngblood

Prepared under Contract No. NAS8-11096 by

NORTHROP SPACE LABORATORIES
Space Systems Section
6025 Technology Drive
Huntsville, Alabama

GROUP 4
Downgraded at 3 year intervals; declassified after 12 years

For

BASE DEVELOPMENT GROUP
PROPULSION AND VEHICLE ENGINEERING LABORATORY

NOTE: This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, USC, Sections 793 and 794. The transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

~~CONFIDENTIAL~~

PREFACE

This report was prepared by the Northrop Space Laboratories (NSL), Huntsville Department, for the George C. Marshall Space Flight Center under authorization of Task Order N-59, Contract NAS8-11096. The NASA Technical Representatives were Messrs. Charles R. Darwin and John C. Rains of the MSFC Propulsion and Vehicle Engineering Laboratory (R-P&VE-AB).

The work completed represents a fifty-five (55) man-week effort commencing on 1 December 1964 and ending 4 April 1965.

The contributions of the following Northrop Space Laboratories personnel to the contents of this report are gratfully acknowledged.

T. Andrisan	J. Hughlett
J. Ard	R. King
S. O. Bresin	W. Lucas
L. Breazeale	M. Sabet
D. Coughlan	D. Schloredt
C. O. DeLong	J. Stanley
D. Dreier	D. Thomas

The invaluable assistance of Mrs. P. Coats and Mrs. B. Whirley, who typed the report , is also gratefully acknowledged.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

TECHNICAL APPENDIX

LIST OF TABLES

LIST OF TABLES

TECHNICAL APPENDIX

NOTATIONS, SYMBOLS AND DEFINITIONS

ACA	Attitude Controller Assemblies
AES	Apollo Extension Systems
AGS	Abort Guidance Section
AOT	Alignment Optical Telescope
APA	Abort Programmer Assembly
ARA	Attitude Reference Assembly
ATCA	Attitude Translation Control Assembly
C & DS	Contols and Displays Subsystem
C/M	Apollo Command Module
CM/SM	Apollo Command Module and Service Module
CDU	Coupling Data Units
CES	Control Electronics Section
CWEA	Caution & Warning Electronics Assembly
DECA	Descent Engine Control Assembly
DSEA	Data Storage Electronics Assembly
ECS	Environmental Control Subsystem
EPS	Electrical Power Subsystem
FCA	Fuel Cell Assembly
GDA	Gimbal Drive Actuators
GOX	Gaseous Oxygen
IFMA	Inflight Monitor Assembly
IMU	Inertial Measuring Unit
LEM	Lunar Excursion Module

NOTATIONS, SYMBOLS AND DEFINITIONS (continued)

LEM/A	LEM Ascent Stage
LEM/D	LEM Descent Stage
LEM/S	LEM Shelter
LFV	Lunar Flying Vehicle
LGC	LEM Guidance Computer
LiOH	Lithium Hydroxide
LR	Landing Radar
LSSM	Local Scientific Survey Module
MOLEM	Mobile LEM
N & GS	Navigation and Guidance Subsystem
OBCEA	Onboard Checkout Electronics Assembly
PCM	Pulse Code Modulation
PCMTEA	Pulse Code Modulation & Timing Electronics Assembly
PLSS	Portable Life Support System
PMP	Premodulation Processor
PSA	Power and Servo Assembly
RGA	Rate Gyro Assemblies
RR/T	Rendezvous Radar/Transponder
RTG	Radioisotope Thermoelectric Generator
SCEA	Signal Conditioning Electronics Assembly
SCI	System Checkout Instrumentation
SCS	Stabilization and Control Subsystem
SI	Scientific Instrumentation
SOX	Supercritical Oxygen

NOTATIONS, SYMBOLS AND DEFINITIONS (continued)

SSA	Space Suit Assembly
TCA	Translation Controller Assemblies
c	Coefficient of soil cohesion, psi
K_c	Modulus of soil deformation due to cohesion ingredients of soil, $lb/(inch)^{n+1}$
K_ϕ	Modulus of soil deformation due to frictional ingredients of soil, $lb/(inch)^{n+2}$
n	A dimensionless factor reflecting stratification of soil
ϕ	Angle of friction (between soil grains), degrees
cg	Center of gravity
c_p	Specific heat at constant pressure BTU/ lb ^{o}F
w	Weight in pounds
A	Surface area in square feet
BTU	British Thermal Unit
lb	Pound
ft^2	Square feet
^{o}F	Temperature in degrees Fahrenheit

SUMMARY

This report is concerned with the modifications required for the conversion of the Lunar Excursion Module (LEM) to; (1) a lunar shelter and (2) a mobile lunar vehicle. In consonance with the present minimum cost philosophy for the AES mission hardware, minimum modification to the LEM subsystems was a stringent requirement throughout the study effort. The two principal additional design requirements placed upon the LEM configuration by the conversions were; (1) increasing the lunar stay from four days to fourteen days with a 50% contingency requirement on essential expendables and (2) the six month dormant period. A previous study[1] served as a guide for the modifications made to the existing LEM configuration.

The capabilities of each LEM subsystem were studied to establish whether the existing subsystem was able to adequately perform the extended mission requirements. When it became apparent that the existing LEM subsystem was not suitable for the extended mission, a modified concept was developed using the minimum modification criteria. The modified subsystems should not be considered the optimum subsystems because of the strong influence of the minimum modification requirement. New subsystem concepts were developed when existing LEM subsystems could not be extended or modified.

Electrical power profiles were established for the active and dormant phases of the mission for the LEM Shelter and the Mobile LEM Vehicle. The ECS system of LEM was modified as required for the extended mission including the addition of an oxygen storage container to conserve cabin oxygen during ingress/egress operations. The scientific instrumentation desired for the LEM Shelter and Mobile LEM missions is tabulated in the report with the weight, volume and power requirements for each instrument. Other equally important subsystem changes are included in the report.

A weight comparison is made for each subsystem (including all components) for the LEM, the LEM Shelter, and the Mobile LEM. The items added to and removed from the LEM ascent and descent stages to accomplish the conversions are tabulated in the Appendix with associated center of gravity data. A Table summarizing all the modifications required for each LEM subsystem to permit its use in the LEM Shelter or Mobile LEM is included in the report.

The study concludes that the LEM may be converted to a two man lunar shelter with a 14 day stay-time and a six month storage period capability. The Mobile LEM concept is not considered feasible inasmuch as major modifications to LEM are required and this violates the minimum modification criteria. The LEM Shelter and MOLEM payload capabilities were determined to be 3, 636 and 1, 878 pounds respectively. This capability may be allocated for scientific instrumentation, mobility aids, leveling equipment, and unloading equipment.

This report was based upon an intensive study of individual LEM subsystems with some attention devoted to interrelated effects of one subsystem upon another. More study is required for the integrated LEM Shelter subsystems before it may be definitely established that the minimum modification criteria is not violated. Subsystems recommended for additional study include the Environmental Control, Electrical Power, Navigation and Guidance, Communications, and the Unloading Subsystem for the LSSM.

SECTION 1.0

INTRODUCTION

As a means of minimizing the costs to be incurred by the planned AES missions, it has been proposed that existing Apollo hardware be utilized to the maximum extent possible. Since the AES missions differ greatly from the initial Apollo mission with respect to mission time, crew activity, and vehicle requirements, the applicability of existing Apollo hardware for use in extended missions must be determined.

The purpose of this report is to present the results of a study conducted to determine the minimum modifications required to convert the Apollo Lunar Excursion Module (LEM) to; 1) a lunar shelter and 2) a mobile lunar surface vehicle. The study effort was based on development of the two derivatives of the basic LEM which could sustain two astronauts on the lunar surface for a period of 14 days. The modifications of the existing LEM for use as a lunar shelter and/or mobile vehicle were considered in previous study [1], and this served as a guide for the subsequent work presented in this report.

Each LEM subsystem was studied to determine its capability and to determine if this capability could be expanded to satisfy the extended mission requirements. When the LEM subsystems were not suitable for the extended mission, a modified concept was developed using the minimum modification criteria. New subsystem concepts were developed when existing LEM subsystems could not be extended or modified.

SECTION 2.0

OBJECTIVES

The primary objectives of the study were:

- To determine the feasibility of converting the Apollo LEM to a LEM shelter (LEM/S) and/or mobile LEM (MOLEM).
- To determine the necessary minimum modifications to LEM to satisfy the LEM/S and MOLEM missions.
- To determine the weight and volume penalty associated with the LEM modifications.
- To determine potential problem areas requiring further analyses.

SECTION 3.0

EXISTING LEM CONFIGURATION

The existing LEM configuration used in this study is shown in Figure 3-1. It can be seen that this configuration consists of an ascent stage and a descent stage, along with the associated subsystems required for performance of the various mission tasks assigned to each stage. The two stages are mated, with disconnect capability from tie-down structure and subsystem umbilicals being provided to accomplish the ascent from the lunar surface, or to abort the mission anytime during descent to the lunar surface. A brief description of each stage and its mission related function will be given in this section.

3.1 LEM ASCENT STAGE

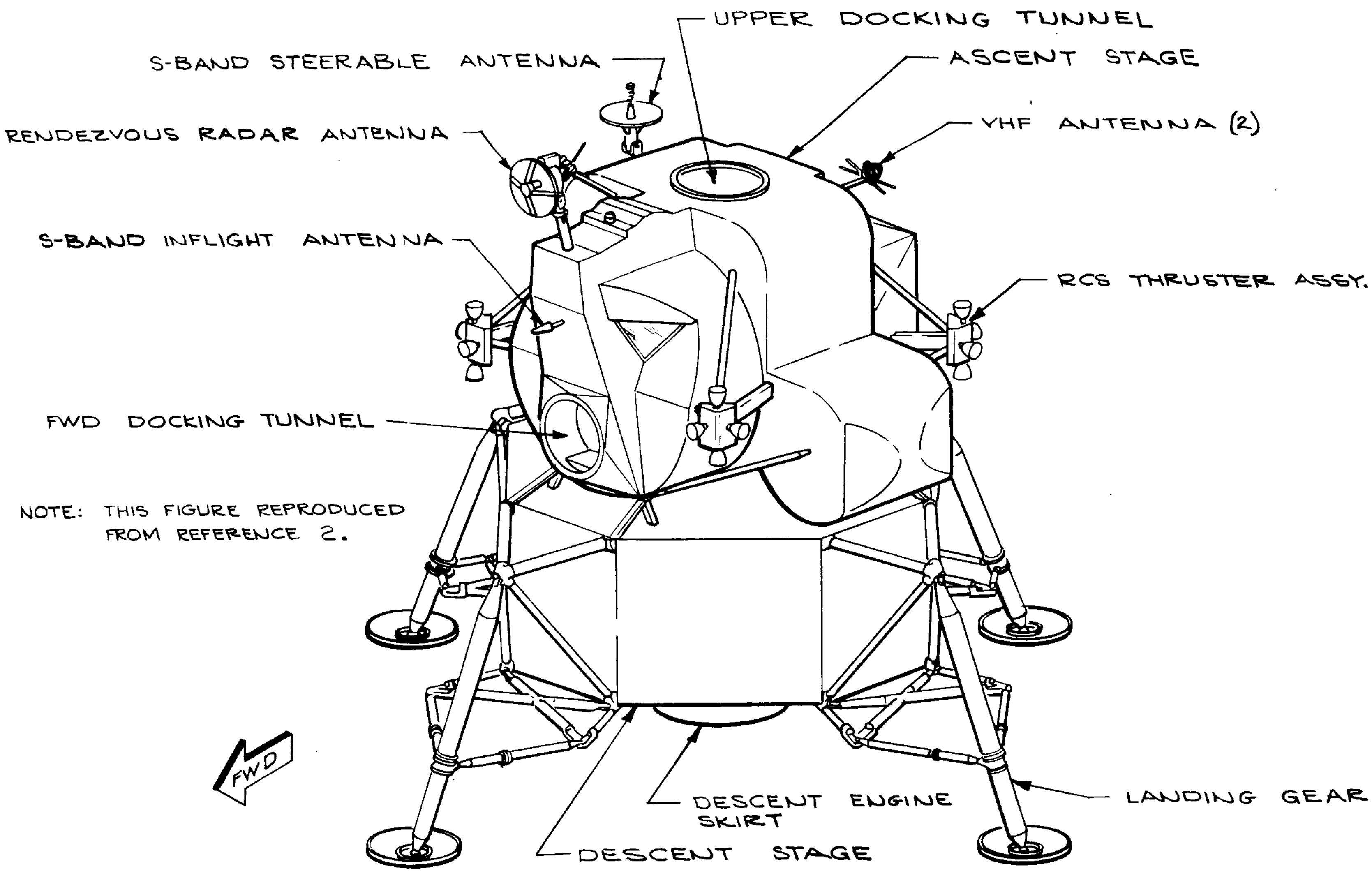
The ascent stage is an enclosure providing the necessary environmental control and life support functions to sustain a two man crew in the hostile lunar environment for a period of up to four days(Figure 3-2). The ascent stage also provides the capability for ascending from the lunar surface (with its two man crew), rendezvousing, and docking with the orbiting command and service modules (CM/SM) to allow the crew to transfer to the command module (CM) for the return trip to earth.

The ascent stage consists of a pressurized crew forward compartment, midsection, and an unpressurized aft equipment bay. Additional ascent stage constituents are; Controls and Displays, Navigation and Guidance Subsystem (N & GS), Environmental Control Subsystem (ECS), Ascent Propulsion Subsystem, and other equally important subsystems.

Each of the ascent stage subsystems will be discussed in more detail in Section 9 of this report.

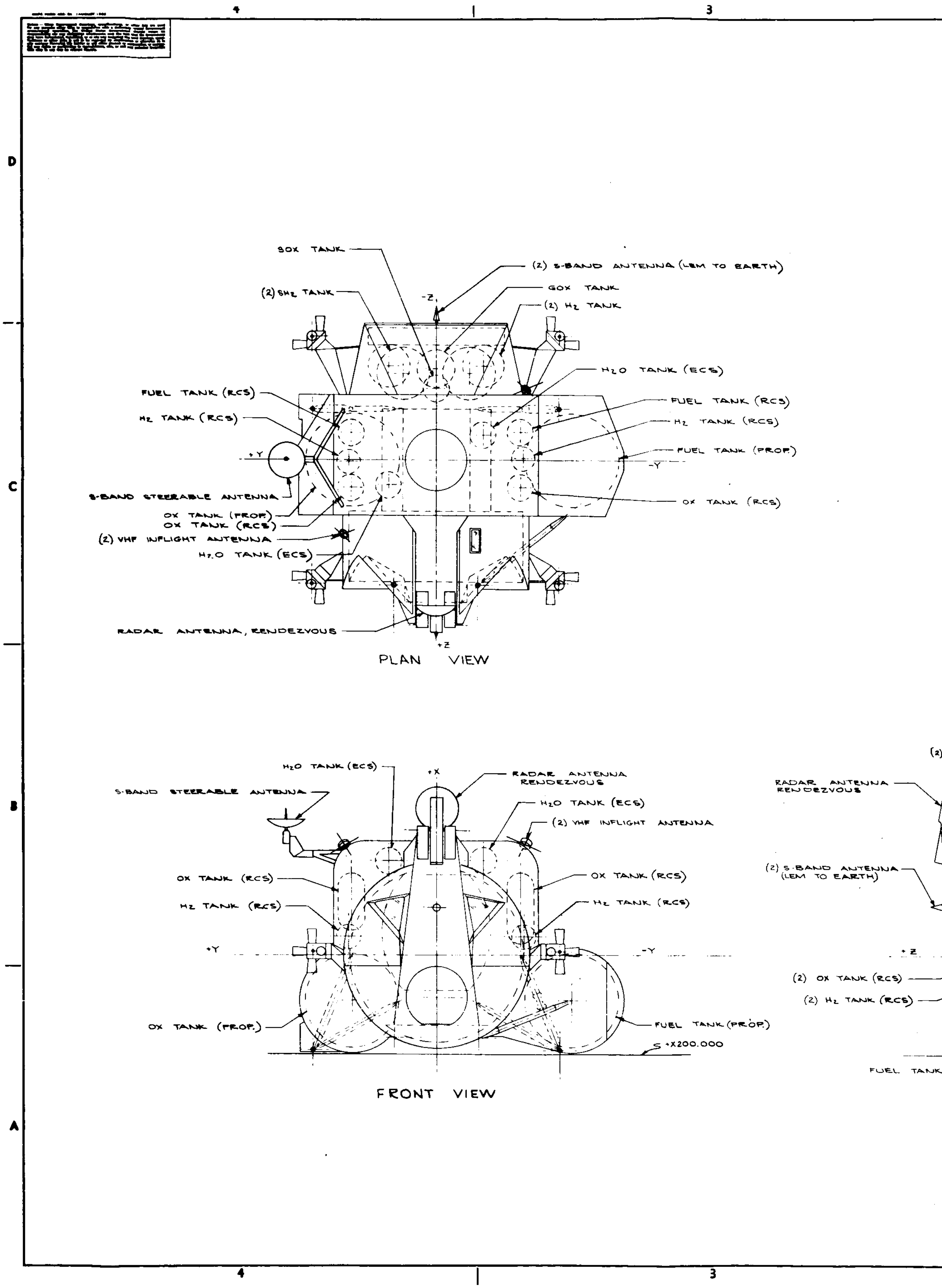
3.2 LEM DESCENT STAGE

The descent stage consists mainly of a Descent Propulsion Subsystem and landing gear (Figure 3.3). The descent stage primary structure consists of two pairs of transverse beams arranged in a cruciform. This structure is surrounded by a thermal shield to form a modified octagon.

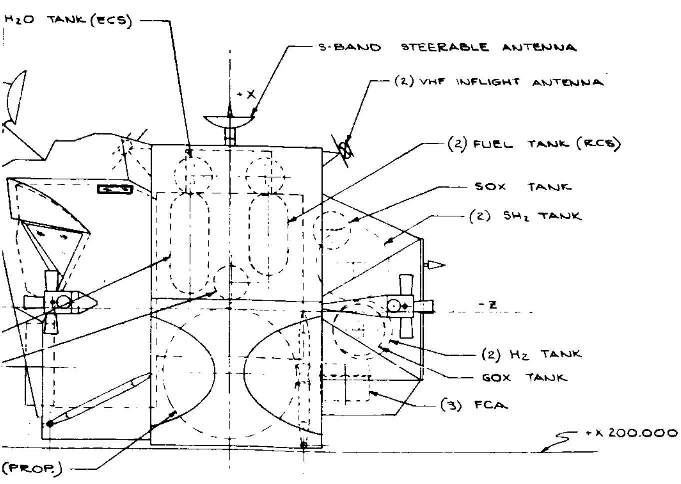


NOTE: THIS FIGURE REPRODUCED FROM REFERENCE 2.

FIGURE 3-1
LEM CONFIGURATION



SOX TANK
(2) S-BAND ANTENNA (LEM TO EARTH)
GOX TANK
(2) H_2 TANK
(2) SH_2 TANK
-Z
H_2O TANK (ECS)
FUEL TANK (RCS)
H_2 TANK (RCS)
FUEL TANK (PROP)
OX TANK (RCS)
+Y
-Y
S-BAND STEERABLE ANTENNA
OX TANK (PROP)
OX TANK (RCS)
(2) VHF INFLIGHT ANTENNA
H_2O TANK (ECS)
RADAR ANTENNA, RENDEZVOUS
+Z
PLAN VIEW
H_2O TANK (ECS)
+X
RADAR ANTENNA RENDEZVOUS
S-BAND STEERABLE ANTENNA
H_2O TANK (ECS)
(2) VHF INFLIGHT ANTENNA
OX TANK (RCS)
OX TANK (RCS)
H_2 TANK (RCS)
H_2 TANK (RCS)
+Y
-Y
OX TANK (PROP.)
FUEL TANK (PROP.)
+X200.000
FRONT VIEW
RADAR ANTENNA RENDEZVOUS
(2) S-BAND ANTENNA (LEM TO EARTH)
+Z
(2) OX TANK (RCS)
(2) H_2 TANK (RCS)
FUEL TANK
4
3
D
C
B
A



SIDE VIEW

FIGURE 3-2

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED

ORIGINAL DATE OF DRAWING 2-19-65

SEE ENGINEERING RECORDS

NEXT ASSY USED ON

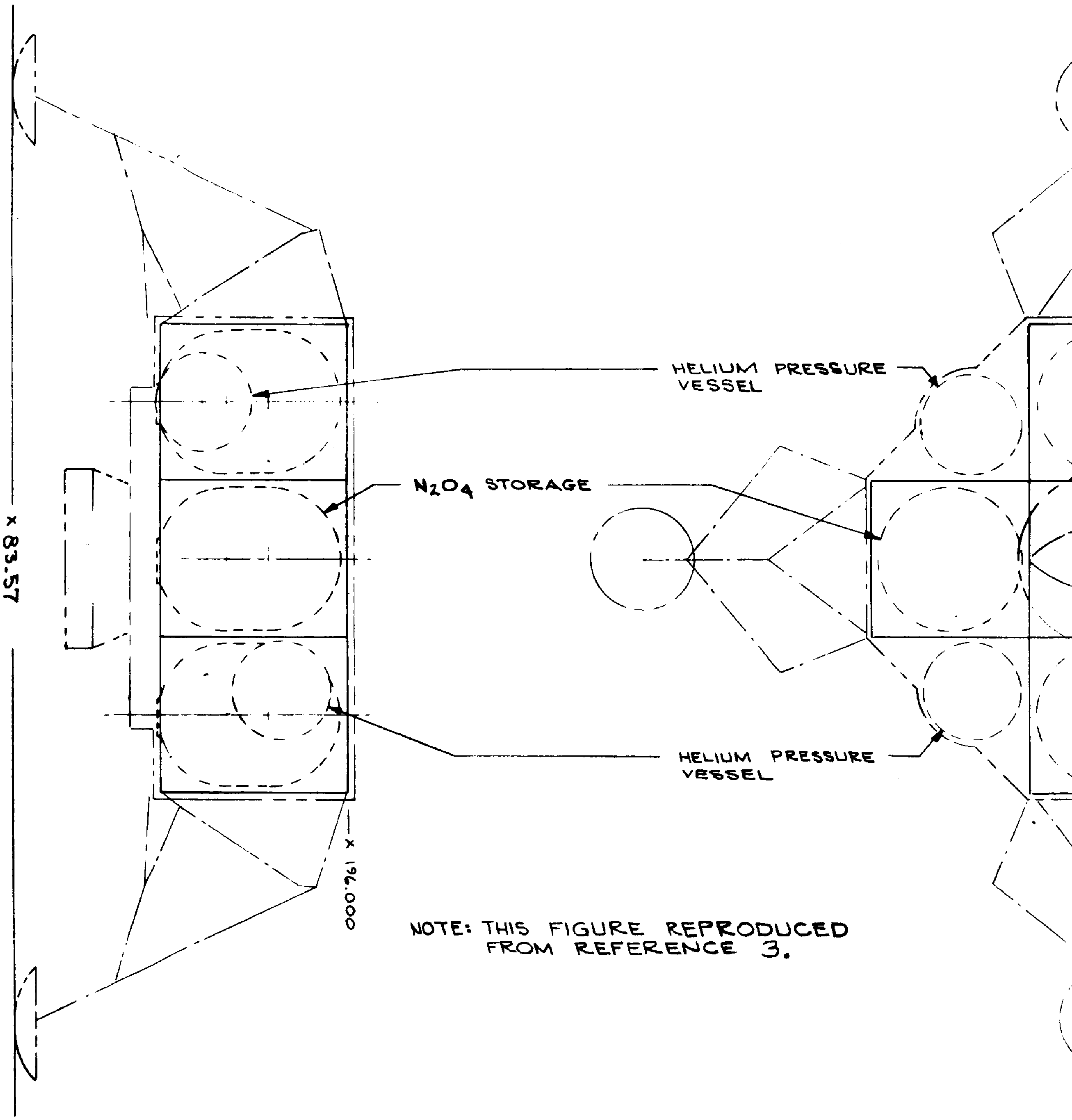
APPLICATION

LEM ASCENT STAGE

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-1

SCALE 1/20


HELIUM PRESSURE VESSEL
N_2O_4 STORAGE
HELIUM PRESSURE VESSEL
x 83.57
x 196.000
NOTE: THIS FIGURE REPRODUCED FROM REFERENCE 3.

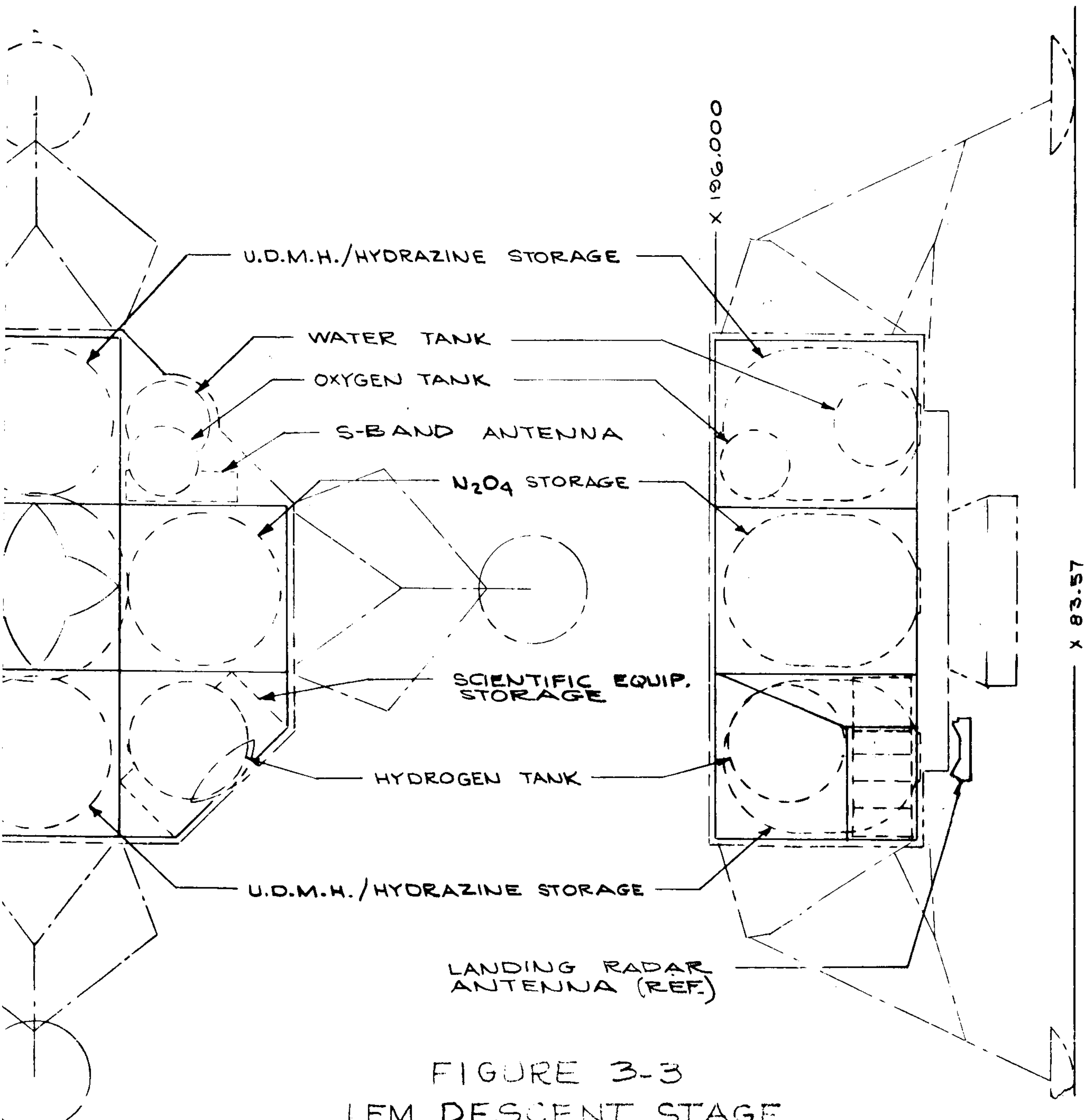


FIGURE 3-3
LEM DESCENT STAGE
GENERAL ARRANGEMENT

FIGURE 3-3

10

The descent stage is unmanned and carries some of the equipment necessary for accomplishing the lunar landing, such as Landing Radar (LR), descent engine, propellant, etc. A water tank, a supercritical hydrogen and a supercritical oxygen tank for use in the ECS and Electric Power Subsystem (EPS) along with some scientific equipment are also carried in the descent stage. In addition to the functions mentioned above, the descent stage acts as a launching pad for the ascent stage upon completion of the lunar surface stay-time.

The descent stage subsystems will be discussed in more detail in Section 9 of this report.

SECTION 4.0

RESTRAINTS AND ASSUMPTIONS

This section defines the Restraints and Assumptions used for this study. The Restraints were considered to have the weight of a specification and could not be changed in the course of this study. The Assumptions were established during this study and previous studies in order to confine the task effort to a narrower field than would otherwise be possible.

4.1 RESTRAINTS

- Minimum modification shall be permitted to all existing LEM subsystems converted for use in the LEM/S and the MOLEM [4].
- The derivatives of the ascent stage shall receive primary emphasis in the conversion of LEM to either a LEM/S or the MOLEM.
- The November 1, 1964, LEM weight statement shall be used throughout this study for the weight comparisons with the LEM/S and MOLEM.
- The crew for the LEM/S and MOLEM shall consist of two men who will be transported to the lunar surface by another LEM.
- The planned mission time shall be up to 14 days (336 hours). In addition, a 50% contingency period shall be provided for all essential life support and ECS expendables.
- A LEM/Truck shall not be used for this study. The RCS, and other LEM/A equipment necessary to support a lunar landing, will remain on the LEM/A and may not be installed on the LEM/D.
- The maximum dormant period on the lunar surface shall be six months.
- The MOLEM and, where applicable, subsystems associated with the LEM/S, shall be remotely unloaded from the LEM/D shortly after arrival on the lunar surface.

- The mobility concepts considered for MOLEM will be confined to four-wheel drive systems only.

4.2 ASSUMPTIONS

- The LEM/S and MOLEM will be operable and inhabitable during both the lunar day and the lunar night.

- The astronaut crew will spend an average of two 4 hour periods each day outside the shelter[5]. This eight hour total time per day for the crew will be devoted to lunar exploration and planned scientific experimentation.

SECTION 5.0

STRUCTURAL DESIGN CRITERIA

The criteria for the structural design of the LEM/S and MOLEM are presented in this section. The criteria for subsystems other than structural are not considered to be within the scope of this report. Criteria for the other subsystems may be obtained from AES reports for that particular subsystem. The structural design criteria are categorized as:

- General Criteria
- Environmental Criteria
- Landing Accelerations
- Structural Safety Factors

5.1 GENERAL CRITERIA

5.1.1 Careful attention shall be paid to the materials selected for use in structural design. The usual requirements for material selection are rigidity, strength, inhibiting of corrosion, wear, etc. The lunar environment will, in addition, pose severe thermal gradients, extremely low temperatures, solar radiation and micrometeorite bombardment all of which must be considered before a final material choice can be made.

5.1.2 The LEM docking adapter may be considered capable of sustaining hoisting loads for all vehicle unloading operations.

5.1.3 The converted LEM/A center of gravity during shipment is assumed to be within 2.5 inches of the AES payload vertical centerline.[6] The cargo deck of the LEM/D is assumed to be at LEM station 200.

5.2 ENVIRONMENTAL CRITERIA

5.2.1 All components shall be protected to withstand the translunar and lunar environments, including the six month dormant period. Specifically, radiation, thermal and micrometerorite protection shall be provided for all components.

5.2.2 The characteristics of the lunar surface, including 5° lunar slopes [6], 24 inch high rocks[6] and the lunar soil bearing strenth shall be considered during the unloading operations.

5.3 LUNAR LANDING ACCELERATIONS (EARTH Gs)

5.3.1 Condition A - 8 gs translational accelerations vertically with maximum angular accelerations of $\pm$ 14 radians/sec^2.

5.3.2 Condition B - 8 gs translational accelerations horizontally with maximum angular accelerations of $\pm$ 14 radians /sec^2.

5.4 STRUCTURAL SAFETY FACTORS

5.4.1 Pressure loads for the manned cabin and tankage.

F.S. = 1.5 for yield strength

F.S. = 2.0 for ultimate strength

5.4.2 For all loadings other than pressure:

F.S. = 1.35 for yield strength

F.S. = 1.50 for ultimate strength

SECTION 6.0

TASK APPROACH AND SELECTION CRITERIA

The task methodology flow chart is shown in Figure 6-1. The design inputs for the LEM/S and the MOLEM include the requirement for minimum modification to existing LEM subsystems. The entire study was strongly influenced (and is consequently biased) by this requirement. In order to provide proper emphasis for the minimum modification requirement an attempt was first made to utilize all of the existing LEM subsystems without change for the LEM/S and the MOLEM missions. In the instances where it was apparent this was not a realistic approach, a practical subsystem was synthesized which satisfied the design inputs, including minimum modification to the LEM. The resulting subsystem was not necessarily the optimum subsystem, rather it is the "practical" subsystem capable of meeting all of the design inputs. The term "minimum modification" was considered to include all rework to LEM which did not involve:

1) Extensive hardware changes; especially those requiring rerouting of major plumbing and wiring runs.

2) Significant structural modifications requiring reanalysis and retesting to establish structural adequacy.

3) Major changes to subsystem components which would have required a long development period and an elaborate proof testing program.

The preliminary design requirements for the LEM/S and the MOLEM were established by taking into account the minimum modification requirement, the mission objectives, the lunar environment, the study restraints and assumptions, and finally the desired reliability goals. The design criteria were formulated considering the design requirements e.g., the remote control unloading requirement was dictated by the unattended six month dormant period and the need for safe separation of the lunar surface vehicle and the LEM stage.

The configurations studied included the LEM/S, MOLEM, the LSSM and the LFV. The subsystems studied included Structure, Stabilization & Control, Instrumentation, Communications, Navigation and Guidance, Propulsion, Reaction Control, Controls & Displays, Electrical Power, Environmental Control, Tiedown, Leveling and Unloading and finally Mobility. A human factors analysis was then performed for the integrated subsystems to establish the desired man-machine relationships for the LEM/S and MOLEM.

After the various subsystem concepts were postulated a comparison analysis was performed and the desired subsystem selected

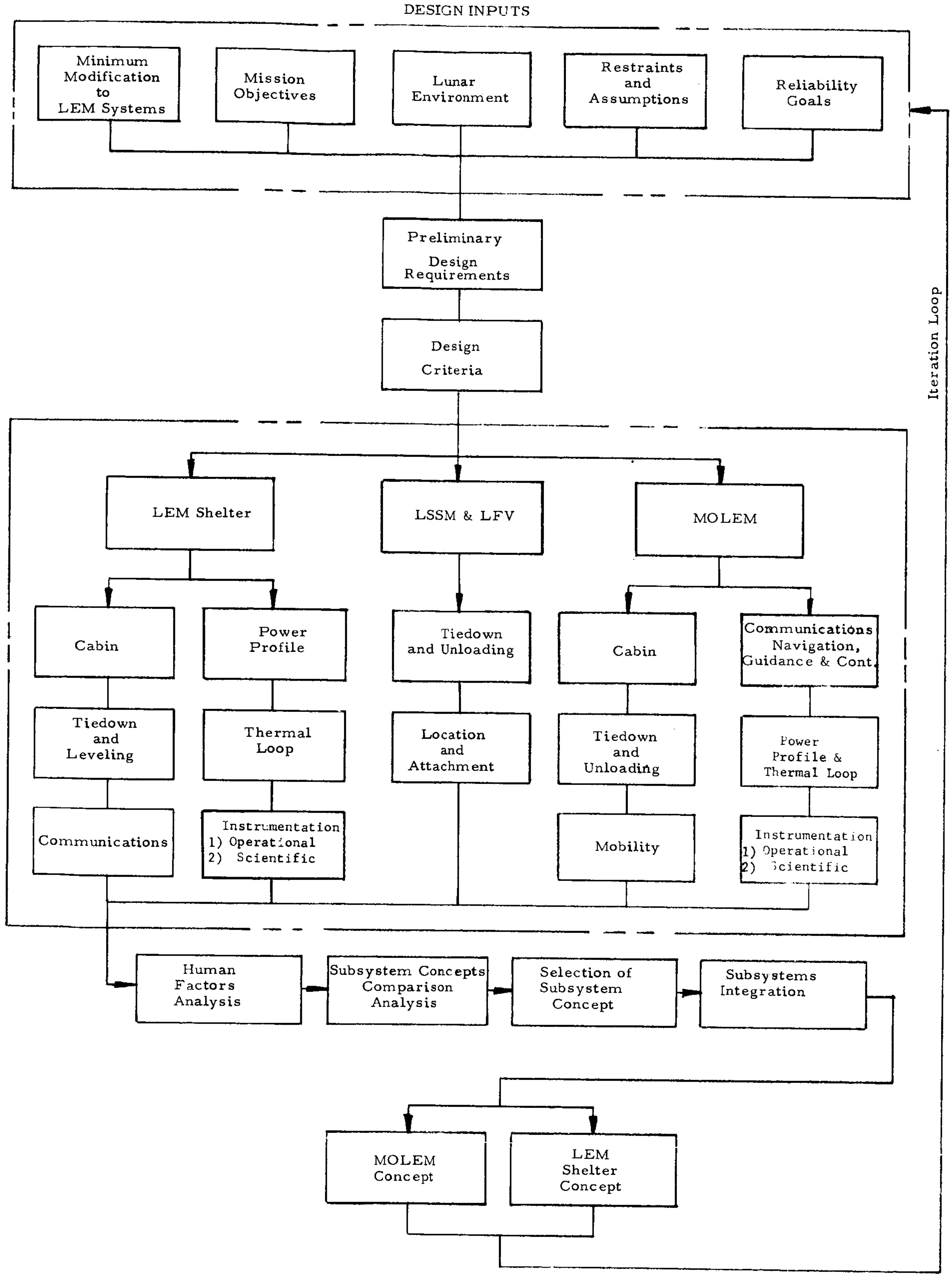


FIGURE 6-1. TASK METHODOLOGY FOR LEM SHELTER AND MOLEM STUDY

for integration with either the LEM/S or the MOLEM concept. An iteration loop is also shown whereby the steps already described were repeated taking into account the effect of interrelated subsystem requirements. This process was repeated until the derived subsystem concepts satisfied the overall configuration requirements.

An earlier study[1] established the significant trends resulting from the conversion of LEM to a lunar shelter and/or mobile vehicle. The results obtained from this initial study served as a guide for the subsequent work presented herein.

SECTION 7.0

INTERFACE CONSIDERATIONS

The interfaces requiring study are discussed in this section and include:

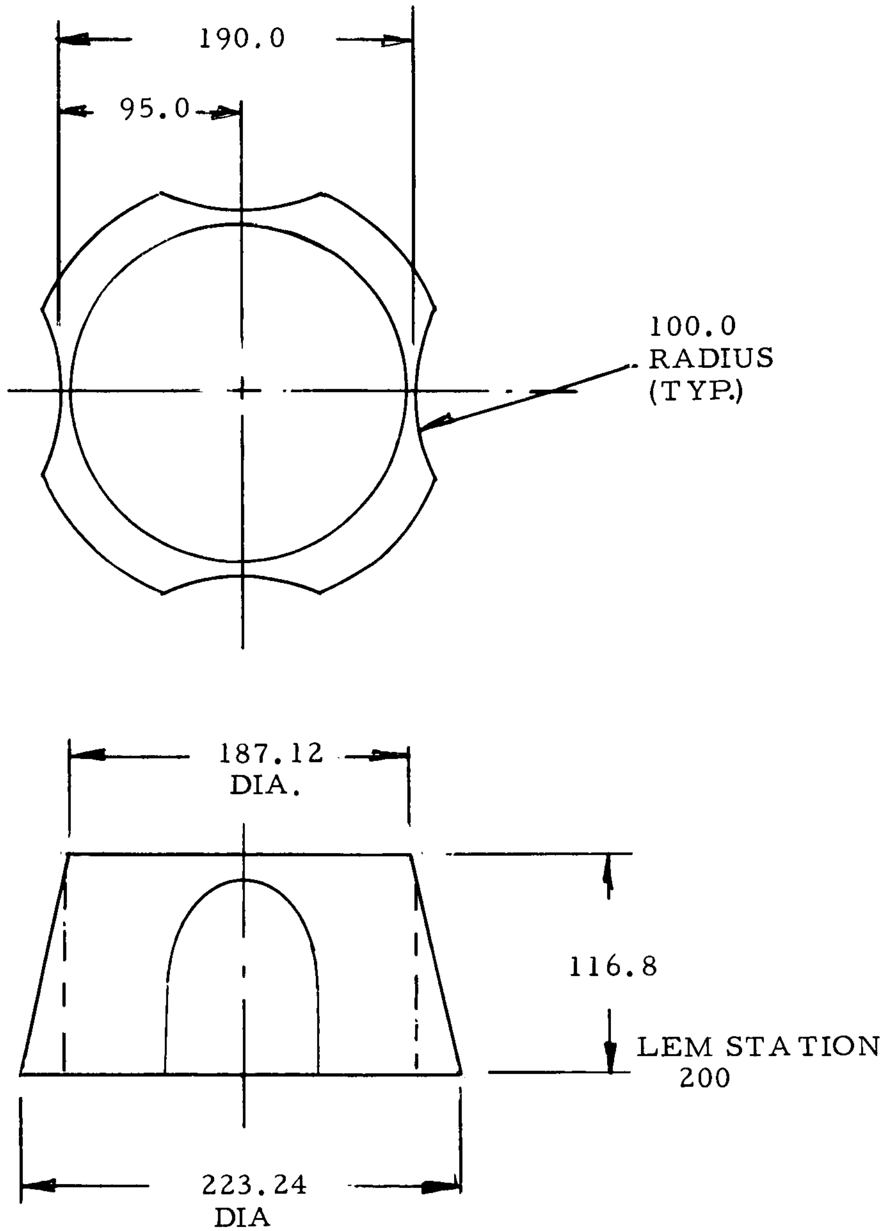
- AES Payload Envelope
- Lunar Surface
- Local Scientific Survey Module
- Lunar Flying Vehicle

7.1 AES PAYLOAD ENVELOPE

The AES Payload Envelope for the LEM/S and MOLEM is presented in Figure 7-1. The converted LEM ascent stage must fit inside of this envelope for both the LEM/S and MOLEM. The four scallops of 100.0 inch radius are a payload envelope clearance constraint. The scallops provide blast path clearances for the Reaction Control Subsystem nozzles located on the ascent stage. The blast path clearance requirement is assumed to be constant over the height of the payload envelope.

7.2 LUNAR SURFACE CONSIDERATIONS

The characteristics of the lunar surface were uncertain at the time of this study. For unloading studies, the maximum lunar slope and the maximum protuberance height were assumed to be 5^{o} and 24 inches respectively[6]. The ELMS[7] model was used to define the characteristics of the lunar surface for the MOLEM mobility studies. It was further assumed that the lunar soil possesses sufficient bearing strength to support the unloading tracks during unloading operations.

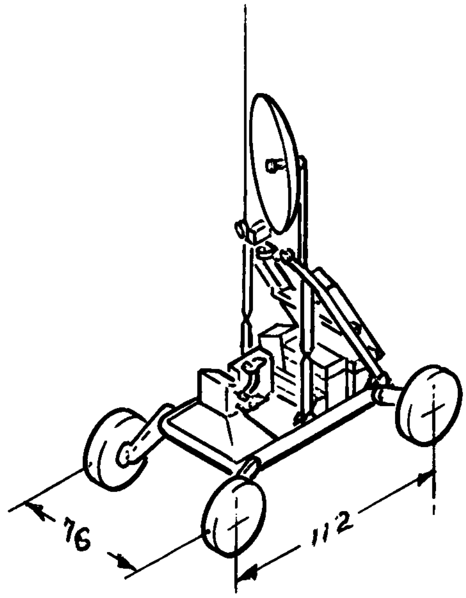


AES PAYLOAD ENVELOPE

FIGURE 7-1

7.3 LOCAL SCIENTIFIC SURVEY MODULE

A small lunar surface vehicle has been considered for use in conjunction with a manned lunar shelter. The purpose of this vehicle is to extend the capability of the AES payload with respect to scientific investigation of the moon. Several LSSM concepts have been developed in a concurrent study[8]. The preferred (1200 lbs) concept has been chosen for presentation here (Figure 7.2).



LSSM CONFIGURATION (WHEELS UNFOLDED)

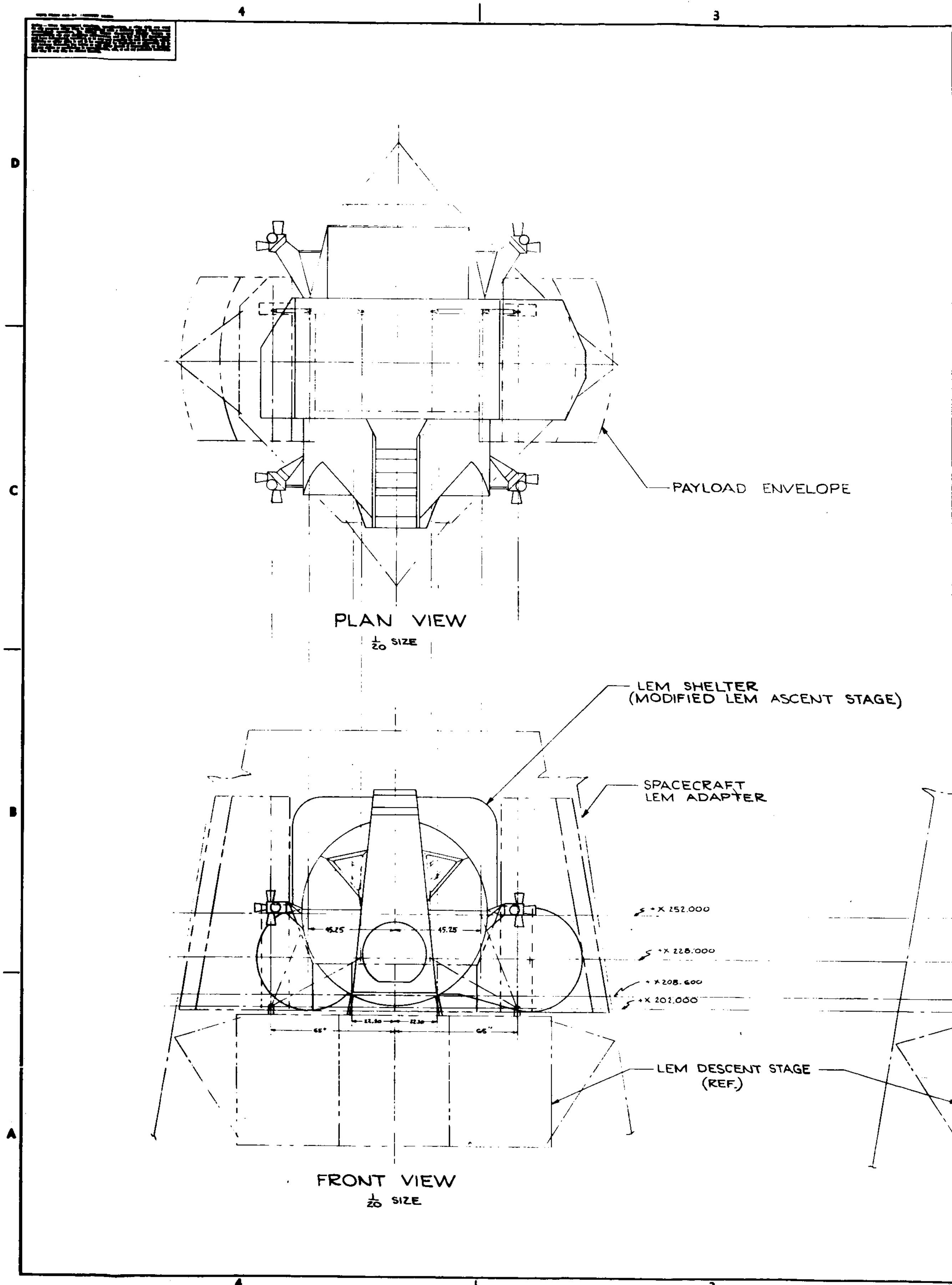
FIGURE 7-2

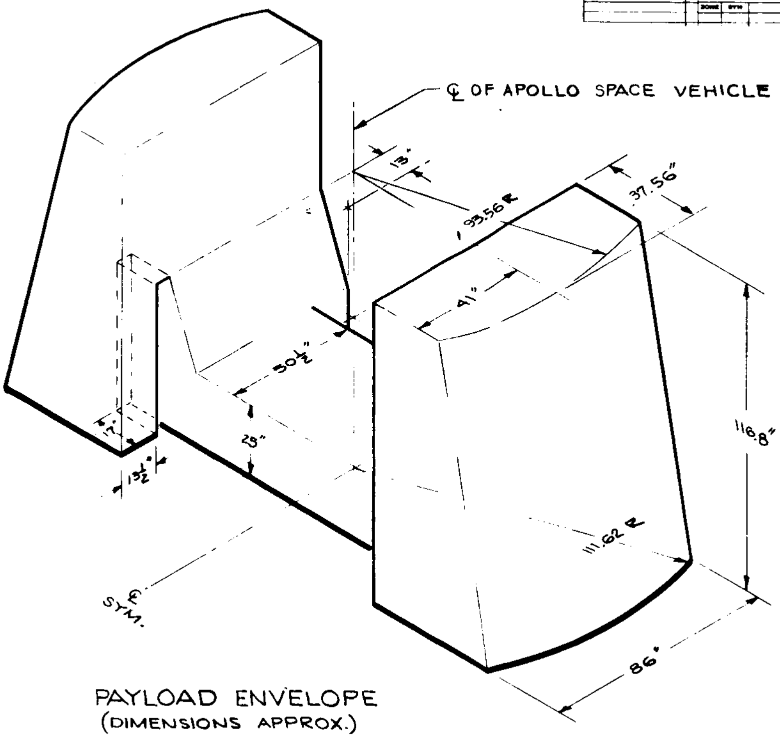
The LSSM has the capability of transporting a space suited astronaut and 330 lbs of scientific equipment to and from points of interest on the lunar surface within a 5 mile (8 km) radius of the LEM/S. The intended duration of a single traverse is six hours. Since the existing LEM PLSS is adequate for only three hours active use, with a one hour contingency, an additional PLSS has been included on the LSSM.

Figure 7-3 shows the LEM ascent stage within the payload envelope. The shaded area indicates the additional storage volume within the payload envelope after removing the ascent propulsion engine tanks. It is in this additional volume that the LSSM must be packaged for the earth-moon flight. This is accomplished by folding the LSSM's antenna and roll bar and manipulating the articulated wheels to obtain the overall vehicle envelope of 36" x 84" x 108".

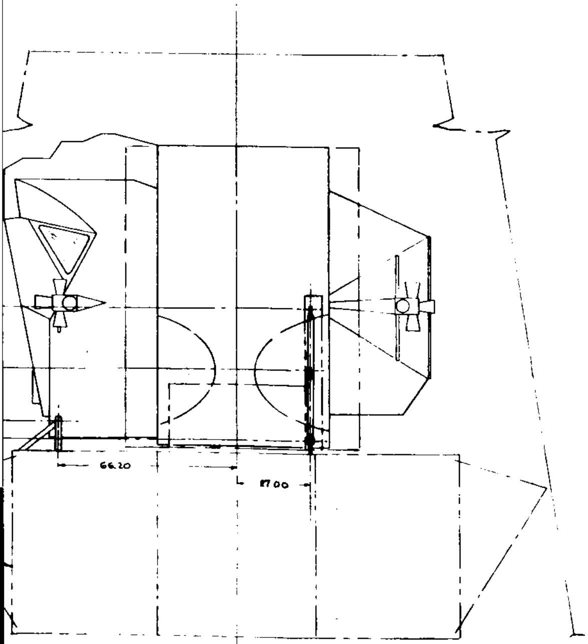
The LSSM is shown in the stowed position in Figure 9-31, along with its tiedown and unloading equipment. The unloading sequence is shown in Figure 9-25.

BLANK PAGE 22


PAYLOAD ENVELOPE
PLAN VIEW
1/20 SIZE
LEM SHELTER
(MODIFIED LEM ASCENT STAGE)
SPACECRAFT
LEM ADAPTER
+X 252.000
+X 228.000
+X 208.600
+X 201.000
45.25
45.25
LEM DESCENT STAGE
(REF.)
FRONT VIEW
1/20 SIZE



PAYLOAD ENVELOPE
(DIMENSIONS APPROX.)



L. H. SIDE VIEW
1/20 SIZE

FIGURE 7-3

REVISIONS

LIST OF MATERIAL

SEE ENGINEERING RECORDS

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED

2-3-65

SUPPLEMENTAL
PAYLOAD
ENVELOPE

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J | N-59-2

SCALE NOTED

7.4 LUNAR FLYING VEHICLE

The use of a Lunar Flying Vehicle (LFV) in conjunction with the LEM/S and/or LEM/S-LSSM combined payload has been considered for extending the LEM/S capability. The LFV may be used as the primary mode of transportation over the lunar surface or, as an emergency vehicle.

No information was generated with respect to the LFV performance or configuration. Based upon preliminary data showing the overall dimensions for the LFV to be 38 x 78 x 67 inches, adequate storage space is available within the LEM/S payload envelope. Adequate payload space is also available in the event both the LSSM and the LFV are used to supplement the LEM/S payload.

The LFV currently under study is in the 1200 lb weight class and if used jointly with the LSSM the scientific equipment weight allocation would be severely penalized. However, due to the lack of available information concerning the LFV, no further consideration was given the vehicle. Instead, emphasis has been placed on the use of the LSSM as the LEM/S supplemental payload.

SECTION 8.0

MISSION DESCRIPTION

Mission analysis studies were conducted for the LEM/S and MOLEM to define the operations and functions to be performed by each throughout their useful mission life, and in order to identify these functions with the appropriate subsystems. Comparison between the currently accepted LEM mission profile and the mission profiles proposed for the LEM/S and MOLEM provides the basis for identifying operational differences between the three configurations.

The basic LEM mission and LEM subsystems were utilized as datum in the analyses of LEM subsystem capability to perform the LEM/S and/or MOLEM mission. The subsystem analyses serve to identify the minimum reasonable (but not necessarily optimum) modifications to LEM necessitated by conversion to a relatively long term lunar shelter or mobile lunar laboratory. The costs (i.e., weight, power, volume, etc.) associated with using the existing LEM systems, with and without change, are identified by these analyses.

8.1 MISSION PROFILES

The mission profiles of the LEM, LEM/S and MOLEM are graphically illustrated in Figure 8-1 to identify the significant mission operational differences between the basic LEM and its derivatives. The most significant mission profile differences are that the LEM derivatives:

1. Do not require capability to ascend from the lunar surface, inject into a precise lunar parking orbit and rendezvous with the Command and Service Modules (CM/SM).

2. Remain on the lunar surface up to 6 months prior to their use by a two man astronaut crew. During this lunar storage time the status of LEM/S and MOLEM subsystems are to be functionally checked by periodic remote commands from Earth. The subsystem status data, and data from selected scientific experiments are to be telemetered to Earth during the storage period.

SUBSYSTEM / MISSION PHASE	REAC
	LEM
EARTH LAUNCH	Pre Out Fun
EARTH-MOON TRAJECTORY	No O
LUNAR PARKING ORBIT	No Oper Check O
DESCENT AND LANDING ON THE LUNAR SURFACE	Separate Service Attitude Engine F Small T
ESTABLISH VEHICLE FOR LUNAR STAY PERIOD	Check-Out For Ascent
DORMANT LUNAR SURFACE OPERATION	Not Applicable
ACTIVE ASTRONAUT USE PERIOD ON LUNAR SURFACE	Check-Out Prior To Departure
LUNAR SURFACE DEPARTURE & ASCENT TO RENDEZVOUS ORBIT	Control Attitude During Ascent. Small Traj. Corrections
RENDEZVOUS AND DOCK WITH COMMAND SERVICE MODULE	Effect Final Docking Maneuvers

FIGURE 8-1

27-1

TION CONTROL		FLIGHT PROPULSION			COMMUNICATIONS	
SHELTER	MOLEM	LEM	SHELTER	MOLEM	LEM	LEM SHELTER
aunch Check Only-No Flight tions		Prelaunch Check Out Only - No Flight Functions			Transmit System Check Out Data To During Prelaunch Check Out-No Fli	
erations Req'd.		No Operations Req'd.			Transmit Critical System Check-O Command/Service Module (Via Um	
tions Req'd. t Prior To Descent		No Operations Req'd Check Out Prior To Descent			Verify Active Video Telemetry And Co Links To Command/Service Modules P Activate Voice Link	
From Command Module. Control During Descent iring. Impart aj. Corrections.		Impart Descent Traj. ΔV. Brake Descent Velocity To Hover. Provide ΔV For Translation & Landing			Provide Voice Link To Command Module And To Earth. Trans. & Receive T.V., Nav. & Guid. Data To CSM	Trans mit Vehicle and Range Rate Dat Receive Nav. & Gu And Earth. Transm Systems Status Dat
No Operational Functions		Check-Out Ascent Sys	No Operational Functions		Manually Erect And Align High Gain S-Band Antenna Fo Transmission Of Telemetery Data & T.V. Data Provide UHF Voice Link To Earth & CSM & CSM Provide VHF Voice Link Between Astronauts When Outside Cabin	Remotely Accept Systems Check Out Transmit Systems Ck. Remote Control of Unloading Operation of LSSM & LFV
No Operations Or Functions		Not Applicable	No Operations Or Functions		Not Applicable	Receive Commands F And LEM Taxi For Sy Operation & Data Acq Systems Ck. Out., Sc To Earth, CSM Or LE
No Operations Or Functions		Check-Out Ascent Prop Prior Dep.			Maintain Voice, Telemetry & T.V. Links Voice Between Astronauts, To CSM When Earth Via LEM, Shelter LEM Or MOLEM Astronaut Is Outside.	Provide T.V. Data & Voice Links & Possible Relay For LSSM & For LFV Provide Data And C Links To Emplaced
Not Applicable		Provide Ascent & Rendezvous Orbit Δv's.	Not Applicable		Maintain, Voice, Telem Links To Earth & CSM. Transmit Nav. & Guid Data To CSM	Telemeter Empl Data To Earth A Departure If Re
Not Applicable		No Operations	Not Applicable		Maintain Telem & Voice Links To Earth & CSM, Transmit Nav & Guid., Rendezvous & Docking Data To CSM	Not App

	NAVIGATION & GUIDANCE			
MOLEM	LEM	LEM SHELTER	MOLEM	LEM
Block House ;ht Function	IMU Heaters On For Temp. Cond.	Prelaunch Checkout !MU Heaters May Be On For Temperature Conditioning.		Fuel Cells Activated For Reliability & Flight Safety-Navi. Power, Inst., ECS & IMU
ut Data To ɔilical ?)	No Operations Or Flight Functions IMU Heaters On	IMU Heaters May Be On		Fuel Cells On. Power ECS, Instru-mentation & IMU Heaters.
nmand ior To Descent	Manual Align IMU-Compare With CSM. Align Abort Guid. Input Descent Tran. Data	Remote Activate & Align IMU To CSM's IMU. Receive Descent Traj. Data In Computer		Provide
ttitude, Range a To Command Mod. d. Data From CSM iit Television & a to Earth & CSM	Provide Data for Automated Control of Descent Trajectory, Descent Braking, Hover And Landing. Provide Data For Telemeter To CSM And Earth. Provide Data To Accept CSM And/Or Earth Transmission Astronaut Display Nav. & Guid. Up Dating Data.			Provide
Remotely r Commands. Out Data To Earth Remote Control of Unloading Operation	Manually Establish Position & Orientation, Confirm With Earth And Command/Serv. Module	Provide Position, Orientation & Vel. Vector Data For LSSM &/Or LFV If Unloaded Remotely	Provide Position Orientation & Velocity Vector Data During Remote Unloading & Use.	Provide Power To System As Required
'om Earth, CSM stem Check Out, iisition. Transmit entific & T.V Data M Taxi On Command	Not Applicable	Confirm Or Restablish Position And Orientation, Accepting Remote Commands & Data From Earth And Command/Service Module		Not Applicable
'o CSM & Earth. ı LOS And To Relay When ommand Scientific Station	Check Out And Align Prior To Departure	Provide Updating & Tracking Data To LFV or LSSM If Used. Assist In Surveying For Scientific Exper. As Required.	Provide Position, Orientation & Velocity Vector Data During Lunar Surface Travel. Provide Surface Nav. & Guid. Data To Astr't Displays. Assist In Surveying In Scientific Exper. As Required.	Provid Power Scientific Experiments Via Battery Recharge & / Or Umbilical As Required.
aced Scientific fter Astronaut uired	Provide Nav. & Guid. Data For Ascent, Parking Orbit & Rendez-vous With CSM	Not Applicable		Provide Power To All Systems As Required
icable	Provide Range, Range Rate And Azimuth To Effect Docking With CSM	Not Applicable		Provide Power To All Systems As Required

ELECTRIC POWER		STABILIZATION & CONTROL		
LEM SHELTER	MOLEM	LEM	LEM SHELTER	MOLE
Prelaunch Check Out. May Have To Power System Check Out Instrumentation, ECS & IMU Heaters If Power Not Avail From CSM Umbilical.			Prelaunch Check Out Only No Flight Functions	
May Have To Power Check Out Instrumentation, ECS & IMU Heaters If Power Not Avail From CSM Via Umbilical			No Operations Or Flight Functions	
Power To Systems As Required			Prelunar Descent Check Out-Align Abort Guidance System-No Flight Functions	
ower To Systems As Required		Transfer Navigation & Guidance System Inputs Into Control Commands To Reac. Cont. Sys. Drive Steerable S-Band Antenna For Tracking, Nav. & Guid. Data.		
Provide Power to Systems as Required For Remote Check Out & Unloading. Provide Continuous Power To Command Receivers & Proportions of ECS		Check-Out For Ascent.	Implement Remote Erection & Alignment Of High Gain S-Band Antenna For Earth Communicati	
Provide Continuous Power To Command Receiver & Portions Of ECS. Power All Systems Intermittently As Req'd For Check Out & Use.		Not Applicable	No Operation Or Function	
Power To Systems As Required. Provide Power To Scientific Exper. Via Umbilical &/Or Battery Recharge As Required. Provide Power To LSSM &/Or LFV During Stand By & Recharge As Required.	Provide Power For Mobility	No Operations Or Functions. Check Out For Ascent Prior To Departure.	Remote Leveling Of Shelter	Assist M Control C Produce Operating Signals F
Provide Power To Emplaced Scientific Station Via Umbilical If Required After Astronaut Depart.		Transfer Nav & Guid. Data Into Control Commands To Reac. Cont. System & Steerable S-Band Antenna.	Not Applicable	
Not Applicable		Transfer Nav. & Guid. Data Into Control Commands To Reac Cont. System & Steerable S-Band Antenna.	Not Applicable	

	UNLOADING, LEVELING & TIE-DOWN		
:M	LEM	LEM SHELTER	MOLEM
	Maintain LEM In A Secure Position	Maintain LSSM And/Or LFV In Secure Position. Shelter Held Secure	Maintain MOLEM In Secure Position.
	Maintain Tie Do[illegible]n Items In Secure Position		
	Maintain Tie Down Items In Secure Position		
	Maintain Tie Down Items In Secure Position During Descent Maneuvers & Landing		
ons	Check Out For Subsequent Operation	Release LSSM &/Or LFV Restraints & Unload-Remotely	Release MOLEM Restraints. Extend Unloading Mechanism Unload MOLEM By Remote Command
	Not Applicable	No Operations or Functions	
nual f Vehicle Dangerous Condition or Display	No Operation Or Function	Release Shelter Restraints & Level. Provide Manual LFV & / Or LSSM Unloading In Event Remote Operation Failed	Provide For Manual Tie Down Release And MOLEM Un-Loading In Event Remote Operation Failed.
	Deploy Tiedown To Permit Ascent Stage Launch	Not Applicable	
	Not Applicable		

SUBSYSTEM / MISSION PHASE	LUNAR SURFACE MOBILITY			ENV
	LEM	LEM SHELTER	MOLEM	LEM
EARTH LAUNCH	SYSTEM NOT APPLICABLE	PROVIDED BY ASTRONAUTS AND/OR AUXILIARY SYSTEMS SUCH AS LOCAL SCIENTIFIC SURVEY MODULE (LSSM), LUNAR FLYING VEHICLE (LFV)	Prelaunch Check Out Only-No Flight Functions	Prelaunch Cl Aerodynamic Dormant Sys Limits.
EARTH-MOON TRAJECTORY			No Operations Or Functions	Reject Fuel Cell Excess Heat Maintai Their I
LUNAR PARKING ORBIT			No Operations Or Functions	Pressurize Cabin Support Astronaut Life Reject Excess Dormant Syster
DESCENT, AND LANDING ON THE LUNAR SURFACE			No Operations Or Functions	Prior To Separation Disconnect ECS Umbilical Hardware Reject Excess H Dormant System Maintain Cabin Pressure And Astr. Life Support.
ESTABLISH VEHICLE FOR LUNAR STAY PERIOD			Unloading Off Descent Stage By Remote Command. Drive to a Safe Separation Distance From Descent Stage.	Maintain Cabin Press. And Life Support. Vehicle Inspection Requires Expendables For One Cabin Egress-Ingress Cycle & One PLSS Replenishment Reject Exces Maintain Dorn Temp. Limits
DORMANT LUNAR SURFACE OPERATION				Not Applicable
ACTIVE ASTRONAUT USE PERIOD ON LUNAR SURFACE			Provide Manual & Remotely Operated Lunar Surface Mobility During Lunar Day Or Night Conditions.	Maintain Cabin Press. & Life Support. Provides Up To 3 Cabin Egress-Ingress Cycles and Six Replenishments of Portable Life Support Systems.
LUNAR SURFACE DEPARTURE & ASCENT TO RENDEZVOUS ORBIT			Not Applicable	Pressurize Cabin & Support Astronaut Life Maintain Systems Within Their Environmental Limits
RENDEZVOUS AND DOCK WITH COMMAND SERVICE MODULE			Not Applicable	Pressurize Cabin & Support Astronaut Life. Maintain Systems With In Their Environmental Limits.

29-1

IRONMENTAL CONTROL		SCIENTIFIC EQUIPMENT			
LEM SHELTER	MOLEM	LEM	LEM SHELTER	MOLEM	LEM
ıeck Out-Protect Systems From Loads And Heating. Maintain tems Within Inoperative Temp.		Prelaunch Check Out Only-No Flight Functions			Sense Syste Prelaunch
Reject Excess Heat From Oper. Sys.	n Dormant Systems Within noperative Temperature Limits	No Known Flight Operations-No Flight Functions. Experiments In Earth-Moon Trajectory Possible			Sense Trans (Via
Heat From Operating Systems. Maintain ns Within Their Inoperative Temp Limits		No Flight Functions Experiments In Lunar Parking Orbit Possible			Provide Systems Status Data To Astronauts Displays.
eat From Operating Systems. Maintain s Within Their Inoper. Temp. Limits		No Flight Functions. Experiments During Lunar Descent And Landing Possible			Provide Nav. & Guid. Data & System Status Data To Astronaut Displays & To Communications Systems For Transmittal To CSM.
Remote Check Out For Subsequent Use. Establish For Up to 6 Mos Dormancy s Heat From Operating Systems. nant Systems Within Their Inoperative		Manually Emplace And Activate Stationary Experiments	Activate Long Term Lunar Environment Measurement Experiments Not Requiring Set Up.		Sense System Status Data For Display & Telemeter To Earth And Command/Service Module. Detect System &/Or Structure Malfunctions. Detect Position &
Reject Excess Heat From Operating Systems Maintain Dormant Systems Within Their Inoperative Temp. Limits. Periodic Check Out Of Entire System During Lunar Day & Night		Not Applicable	Provide Data On Lunar Environment Using Equipment Not Requiring Set-Up		Not Applicable
Provide Cabin Pressurization & Life Support During 14 Days (Lunar Day & Lunar Night) Operation. Provide For Approximately 30 Astronaut Egress-Ingress Cycles and Replenishments Of Portable Life Support Systems For Twenty Eight 4 Hour Periods Of Lunar Surface Activity		Provide Portable Equipments For Astronaut To Conduct Surface Surveys On Lunar Topography Geology, Seismology & Geophysics.	Provide For Subsurface Exploration Of The Moon. Set Up Long Duration Lunar Environment Exp.		Sense System S To Earth And/C Postion & Orie Stability & Con To Earth And/C System And/Or Check Out For Ascent A
Not Applicable		Not Applicable	Establish Emplaced Scientific Station For Continued Post Astronaut Departure Operation		Provide Nav. & Guid & System Status Data To Astronaut Displays & To Communications For Transmital To Earth/CSM.
Not Applicable		No Known Experiments	Not Applicable	Not Applicable	Provide Nav & Guid & System Status Data To Astronaut Displays & To Communications For Transmittal To CSM

INSTRUMENTATION		DISPLAYS & CONTROLS			CREW PRO	
LEM SHELTER	MOLEM	LEM	LEM SHELTER	MOLEM	LEM	LEM SH
ms Functional Capabilities For :heck Out-No Flight Functions		Prelaunch Check Out Only-No Flight Functions			Prelaunch Check Ou Func	
Systems Status For mittal To Command Module 'mbilical).			No Flight Functions			No Flight
		Display Nav & Guid Info & System Status Data To Astr. Provide Astr. With N & G Manual Overide Control	No Flight Functions		Provide 2 Astronauts Space & Seating For System Monitoring & Control Prior To Descent.	
Sense Systems Status, Nav. & Guid. Data For Transmittal To Command Module. Activate Communications System Upon Landing To Permit Receipt Of Earth Signals For Remote Co.:trol Operations.		Display Nav. & Guid. Info & System Status Data To Astronaut.Provide Astronaut With N & G Manual Overide Control & Control Of Other Systems.	No Flight Functions		Provide Astronauts With Life Support System Monitoring & Control Space, During Descent And Landing. Provide Landing Flare To Assist Visibility At Landing	
Sense System Status, Data For Transmittal To Earth And Command Service Module. Activate Systems For Remote Check-Out On Commands From Earth And/Or Command/Service Module : Orientation Data From Nav. & Guid.		Display System Status Nav. & Guid. Data To Astronauts. Provide System Controls To Astronauts	No Function		Provide (In Cabin) Astronauts With Life Support, System Monitoring & Control Space, Provide Food Stuffs, Hygienie Care Facilities & Exterior View Ports. Provide Life Support Equip. For Outside Astronaut	N
Sense System Status Data For Transmittal To Earth And Command Service Module. Activate Systems For Remote Check-Out And Operation On Commands From Earth.		Not Applicable	No Function		Not Applicable	N
tatus Data For Display & Telemeter r Command/Service Module. Detect, ntation Data From Nav. & Guid. And rol Systems For Display & Telemeter Dr Command/Service Module. Detect Structure Malfunctions. ssist LSSM &/Or LFV		Display System Status, Navagation & Guidance Data Provide Manual Controls Of All Systems To Astronauts. Display Equipment Malfunction Data			Provide (In Cabin) Astronauts Monitoring & Control Space. Hygienic Care Facilities, Ext Life Support System Replenis Interior Lighting & Crew Res	
		Display data Pertinent To LEM-CSM Rendezvous Opportunities.	Provide Remote Control of LSSM/LFV	Provide Displays & Controls For Lunar Surface Traverse.	4 Days Lunar Surface Operation.	Provide I Oper. Pr 14 Days I Continger
Not Applicable		Display Nav. & Guid. & System Status Data To Astronauts. Provide Astronaut Manual Control Of Trajectory & System Operation	Not Applicable		Provide Space & Life Support Equip. For Astronaut Operation. Protect Astronaut From Launch Loads.	
Not Applicable		Display Nav & Guid. & System Status Data To Astronauts. Provide Manual Control For Final Docking With CSM	Not Applicable		Provide Space & Life Support Equip. For Astronaut Operations. Provide Means For Transfer To CSM	

NOTE: "CSM" IS USED AS ABBREVIATION FOR THE APOLLO COMMAND AND SERVICE MODULE.

NO REQD PER ASSY

ASSY DASH NO

SEE ENGINEERING RECORDS

NEXT ASSY | USED ON

APPLICATION

VISIONS		STRUCTURE		
:ELTER	MOLEM	LEM	LEM SHELTER	MOLEM
ıt Only-No Flight tions.		Provide Prelaunch Check-Out Access Via Inspection Openings & Umbilicals. Sustain Launch-Injection Loads		
Functions		Sustain Midcourse Docking Loads Sustain Loads Resulting From Extension Of Descent Stage Landing Legs.		
No Flight Functions		Sustain Cabin Pressure Loads		
Possible Use of Landing Flare To Aid Remote Control of Landing		Sustain Descent Engine And Reaction Control Engines Thrust Loads. Withstand Lunar Landing Loads.		
o Operations Or Functions		Sustain Cabin Pressure Loads & Astr. Egress-Ingress Cycle Loads Sustain S-Band Antenna Erection & Alignment Loads. Sustain T.V. Alignment & Pointing Loads.	LSSM &/Or LFV Unloading Mechanism Loads	Withstand Unloading Loads & Loads From Lunar Mobility System (Shock, Vibration & Twisting)
› Operations Or Functions		Not Applicable	Withstand Thermal Cycling Loads & Micrometeorites	Withstand Thermal Cycling Loads & Micrometeorites
With Life Support System Provide Food Stuffs, Water, ;erior View Ports & Portable hment Supplies. Provide t & Exercise Equipments. Exterior Lighting For Lunar Night ovide Necessary expendables For unar Day & Night Oper. + 50% icy on Essential Expendables		Sustain Cabin Pressure Loads & Astronaut Egress-Ingress Cycle Loads. Provide Inspection, Maintenace And Repair Access. Protect Astronauts From Radiation & Micrometeoroid Hazards.	Withstand Leveling Mechanism Loads. Umbilical Loads For LSSM/LFV Replenishment & Or Standby	Withstand Vibration Shock & Torsion Loadings From Mobile Operation On Lunar Surface
Not Applicable		Sustain Ascent Launch Loads And Cabin Pressure Loads.	Not Applicable	
Not Applicable		Sustain Rendezvous Maneuvering & Docking Loads. Permit Astronaut Transfer To CSM.	Not Applicable	

FIGURE 8-1

ZONE	FIND NO OR ITEM NO	MFR CODE	PART OR STOCK NO / DRAWING NO	REV	D/A	EPL	NO REQD	NOTES	SPECIFICATION, STANDARD OR REMARKS / DESCRIPTION	STOCK SIZE	MATL SPEC	FINISH CODE	HT	UNIT WT

LIST OF MATERIAL — DISTR CODE

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON FRACTIONS DECIMALS ANGLES
MATERIAL
HEAT TREATMENT
FINAL PROTECTIVE FINISH

ORIGINAL DATE OF DRAWING April 4/65
DRAFTSMAN Rodhoff CHECKER
CHECKER Ligacki STRESS
ENGINEER Bresin ENGINEER
SUBMITTED
APPROVED
DIRECTOR

MISSION PROFILES

WEIGHT CHECKER | DATE | CODE
SCALE | UNIT WEIGHT

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

DWG SIZE J N-59-3
SHEET OF

B

A

1

302

3. Provide two astronauts shelter, life support and personal care facilities for a period up to 14 Earth days during conditions of lunar day and lunar night. Twenty-eight (28) or more cabin ingress/egress cycles are anticipated to result from astronaut activity during the 14-day period; resulting in twice that number (56+) depressurizations of the cabin, unless an airlock is incorporated.

The LEM/S derivative has the unique requirements of providing for:

1. Remote checkout and unloading of auxiliary payloads consisting of the LSSM and/or the LFV. Either or both of these payloads are to be delivered to the lunar surface as part of the LEM/S payload.

2. Leveling of the LEM/S pressurized cabin.

8.2 AFFECTED LEM SUBSYSTEMS

LEM subsystems affected by the mission operations of its derivatives and the changes in functions of these systems are tabulated in Figure 8-1.

The modifications to the basic LEM and its systems which must be accomplished to permit its use as a Lunar Shelter or Mobile Laboratory are discussed in the following sections of this report.

SECTION 9.0

SUBSYSTEM STUDIES

As previously stated, the purpose of this study is to define the minimum modifications required for the existing LEM, to satisfy the extended 14 day lunar stay-time mission. To accomplish this, with due consideration being given the minimum modification concpet, each of the LEM subsystems were investigated to determine the overall subsystem function, and the functions of the subsystem assemblies. The approach for establishing the required modifications was as follows:

1. The feasibility of extending the existing LEM subsystem capability to satisfy the longer duration mission was determined.

2. The weight and volume penalty associated with (1) was determined.

3. Where the weight and volume found in (2) was excessive, the subsystem was modified to satisfy the minimum extended mission requirements, (while making use of existing hardware to the maximum extent possible).

4. Where the existing subystem could hot be extended, or modified a new subsystem concept was developed.

This section discusses the existing LEM subsystems and their applicability to the LEM/S and MOLEM missions.

9.1 PROPULSION SUBYSTEM

The propulsion subsystem consists of liquid propellant rocket engines, propellant storage, pressurization and feed components.

The propellant used is a 50-50 mixture of unsymmetrical dimethylhydrazine and hydrazine for fuel, with nitrogen tetroxide for the oxidizer. The mixture ratio of oxidizer to fuel is 1.6 to 1 by weight. The propellants are supplied from baffled tanks with helium being used as the tank pressurant. The helium is stored at 3000 psi in spherical tanks.

The existing LEM propulsion subsystem will be discussed in more detail in the ensuing pages, along with the propulsion subsystems considered necessary for use in the LEM/S and MOLEM.

9.1.1 LEM

The LEM utilizes two separate propulsion subsystems, i.e., Ascent and Descent Propulsion Subsystems.

The Ascent Propulsion Subsystem utilizes a fixed, constant-thrust rocket engine. The engine develops 3500 pounds of thrust in a vacuum, which is sufficient to launch the ascent stage from the lunar surface to the ascent transfer orbit (approximately 50, 000 ft.).

The ascent stage propellant is stored in two large tanks on either side of the ascent stage (Figure 3-2). The helium used in the pressurization assembly is stored in two spherical tanks in the aft equipment bay.

The Ascent Propulsion Subsystem is contained entirely within the ascent stage. The ascent engine is mounted on the centerline of the ascent stage midsection. To stay within the envelope of the ascent stage, the midsection floor to ceiling clearance has been significantly compromised, i.e., a portion of the ascent engine extends into the midsection leaving insufficient standing room for the crew. An engine cover has been placed over this portion of the engine.

The Descent Propulsion Subsystem utilizes a gimbaled deep throttling rocket engine, two fuel tanks, two oxidizer tanks and associated pressurization valves and piping. The engine thrust range is 1, 050 lbs minimum to 10, 500 lbs maximum in a vacuum environment. The Descent Propulsion Subsystem is contained entirely within the descent stage.

The Descent Propulsion Subsystem is used to inject the LEM into an elliptical Hohmann descent transfer orbit with a pericynthion of 50, 000 ft. At the pericynthion of the descent transfer orbit,the descent engine is fired to initiate powered descent to within three (3) feet of the lunar surface.

The ascent and descent propulsion subsystem weights are given in Table 9-1.

[redacted]

TABLE 9-1 PROPULSION SUBSYSTEM WEIGHTS*

PROPULSION SUBSYSTEM	PROPULSION					
	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
PROPULSION SUBSYSTEM	(5236.3)	(17529.8)		(17529.8)		(17529.8)
PROPELLANT	(4675.7)	(16086)		(16086)		(16086)
Usable - Ascent	4625.7					
- Descent		15920		15920.0		15920.0
Trapped - Ascent	50.0					
-Descent		166.0		166.0		166.0
PROPELLANT SYSTEM	(194.2)	(510.6)		(510.6)		(510.6)
Fuel Tanks - Ascent	89.6					
-Descent		225.0		225.0		225.0
Oxid. Tanks -Ascent	89.6					
-Descent		225.3		225.3		225.3
Plumbing - Ascent	15.0					
-Descent		60.3		60.3		60.3
PRESSURIZATION SYSTEM	(162.4)	(525.5)		(525.5)		(525.5)
Helium Tanks - Ascent	124.0					
-Descent		445.0		445.0		445.0
Helium - Ascent	13.5					
-Descent		48.6		48.6		48.6
Plumbing -Ascent	24.9					
-Descent		31.9		31.9		31.9
ENGINES	(204.0)	(407.7)		(407.7)		(407.7)
Engine - Ascent	196.0					
- Descent		370.0		370.0		370.0

[redacted]

[redacted]

TABLE 9-1 PROPULSION SUBSYSTEM WEIGHTS (cont'd)*

PROPULSION SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
Shield - Ascent						
- Descent						
Gimbal Actuators *						
Engine Mount - Ascent						
- Descent		16.7		16.7		16.7
Misc. - Ascent	8.0					
-Descent		21.0		21.0		21.0
Total Propulsion - Inert	(610.6)	(1443.8)		(1443.8)		(1443.8)
Total Propulsion - Expendable	(4625.7)	(16086.0)		(16086.0)		(16086.0)

* Included in Stabilization and Control

9.1.2 LEM Shelter

The demands placed on the propulsion subsystems by the AES LEM/S mission require only that the LEM/S be landed on the lunar surface. No ascent capability is necessary. Therefore, the ascent propulsion subsystem aboard the existing LEM serves no useful purpose aboard the LEM/S.

The LEM/S mission will obviously require additional life support expendables. Also, since the longer mission will be oriented toward obtaining more scientific information about the moon than the LEM mission, a much larger percentage of the total weight will, and should be allocated to scientific equipment, Therefore, it is both necessary and advantageous to consider removal of those subsystems serving no useful function with respect to the extended LEM/S mission. The obvious subsystem to be eliminated from the LEM/S is the entire Ascent Propulsion Subsystem. The propulsion tanks are mounted to the LEM/A with struts, therefore, the removal of the tanks is not a major modification. The descent propulsion subsystem is required for lunar landing and was left intact. The LEM/S propulsion subsystem weight is shown in Table 9-1.

9.1.3 MOLEM

Since the MOLEM mission requirements are the same as those for the LEM/S, the same propulsion subsystem modification applies. The MOLEM propulsion subsystem weight is also given in Table 9-1.

9.2 NAVIGATION AND GUIDANCE SUBSYSTEM

The LEM Navigation and Guidance Subsystem (N&GS) will be reviewed in this section and compared to LEM/S and MOLEM requirements.

9.2.1 LEM

The LEM N&GS consists of the Landing Radar (LR), the Rendezvous Radar/Transponder (RR/T), the Inertial Measuring Unit (IMU), the Alignment Optical Telescope (AOT), the Power and Servo Assembly (PSA), the LEM Guidance Computer (LGC) and five Coupling Data Units (CDU). The N&GS provides data for maintaining the flight trajectory during lunar landing, ascent and rendezvous and docking.

The N&GS is primarily an aided inertial subsystem. The AOT is used to obtain star sightings as a means of inertial reference for the IMU. The LR is used to obtain altitude and velocity information (during descent to the lunar surface)to update inertially derived data. Also during descent, the RR/T tracks the CM to furnish range, range rate and angle rate data to the LGC, to determine the deviation from the required trajectory. The LGC calculates the necessary attitude and thrust vector commands to be transmitted to the Stabilization and Control Subsystem (SCS).

The IMU is the primary inertial sensing element aboard LEM. The IMU senses velocity and attitude changes along three orthogonal axes. These velocity and attitude changes are applied to the LGC which calculates the gimbal angles required to bring LEM to the desired attitude. The calculated gimbal angles are then compared to the actual gimbal angles. In the event a discrepancy exists between the actual and calculated gimbal angles, steering error signals are generated by the LGC, which are applied to the SCS to correct the LEM attitude.

All attitude error signals generated by the LGC are transmitted to the SCS via the CDU's. The CDU's convert and transfer information between the N&GS and the SCS.

The N&GS weights are shown in Table 9-2.

9.2.2 LEM Shelter

In view of the functions of the various N&GS assemblies described in Section 9.2.1, none of the existing LEM N&GS equipment

TABLE 9-2 NAVIGATION AND GUIDANCE SUBSYSTEM WEIGHTS*

NAVIGATION & GUIDANCE SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
NAVIGATION AND GUIDANCE	(276.9)	(28.0)	(304.9)	(28.0)	(276.9)	(28.0)
GFE	(198.5)		(198.5)		(198.5)	
IMU						
AOT & Eyepieces						
LGC						
PSA-CDU						
Star, Maintenace Book						
Cabling						
Navigation Base						
Cold Plate						
RENDEZVOUS RADAR	(78.4)		(78.4)		(78.4)	
Gimbaled Antenna & Boom	26.2		26.2		26.2	
Electronics	32.1		32.1		32.1	
Transponder	17.6		17.6		17.6	
Transponder Antenna & Waveguide	2.5		2.5		2.5	
LANDING RADAR		(28.0)		(28.0)		(28.0)
2-Position Antenna		18.0		18.0		18.0
Electronics		10.0		10.0		10.0
BEACON TRANSMITTER			(10)			
ANTENNA			(10)			
POSITION PLOTTER			(8)		*	
DIRECTIONAL & VERT. GYRO					**	

* See C & DS for weight of this item.

** IMU will be modified for lunar traverse.

can be eliminated if the LEM/S is to be successfully landed on the lunar surface in the unmanned mode. The method to be used in selecting a final lunar landing point will greatly influence the N & GS equipment required. Further studies are considered necessary to determine if obstacle avoidance equipment should be developed, or whether homing devices such as beacons can be used to accomplish the unmanned lunar landing.

After the unmanned lunar landing has been completed the N & GS is of no further use until the arrival of the manned LEM. At this time the LSSM, which will have been unloaded from the descent stage, will be used as a means of conveyance from the LEM to the LEM/S. To accomplish this phase of the mission some additions to the N & GS will be required. These additions are:

- Beacon transmitter
- Antenna (6 meter monopole)
- Position plotter
- Command panel

The Beacon transmitter will provide a homing signal for the LSSM. This beacon will be required on the LEM/S when remote control of the LSSM is required. The 6 meter monopole antenna is required to radiate the homing signal. The position plotter should be used to aid in the remote control operation of the LSSM. The command panel consists of the required controls for the remote mode of operation. A computer and sextant are also necessary, however the onboard LGC and AOT can adequately satisfy these requirements.

The resulting increase in LEM/S N & GS weight compared to the existing LEM is 33 lbs. The subsystem weights are tabulated in Table 9-2.

9.2.3 MOLEM

The existing LEM N & GS equipment will not be changed for the MOLEM mission since all existing components as described in Section 9.2.1 will be used during the descent to the lunar surface. The additional N & GS equipment required for the lunar traverse phase of the mission is shown in the Controls and Displays Subsystem, Section 9.11.3.

and includes an odometer and position plotter. Modifications are assumed permitting adaptation of the IMU for use as N & GS gyros. The beacon transmitter with antenna, installed on the LEM/S, is a low power device and is for communication with the LSSM only. This item is not required for MOLEM. The subystem weights are shown in Table 9-2.

9.3 CREW PROVISIONS SUBSYSTEM

Crew provisions include such items as space suits, PLSS's crew restraints, crew stations, food, etc. These items will be discussed for each of the configurations being considered.

9.3.1 LEM

The LEM crew provisions include a space suit assembly, a waste management section, a restraint assembly and crew stations.

The space suit assembly (SSA) utilizes a space suit and helmet (an anthropomorphic, closed circuit, pressure vessel enveloping the entire crewman), a PLSS, telemetry and communications equipment, biomedical and environmental sensors, emergency oxygen, thermal overalls, a micrometeoroid garment, boots, gloves and a constant wear undergarment. The entire SSA is used when the astronaut is outside the LEM. Under normal operating conditions the entire SSA, with the exception of the PLSS, is worn by the crewmen while inside the shelter with the helmet face plate open. During this time an umbilical from the suit recirculating assembly is attached to the suit for revitalizing the oxygen in the suit.

The PLSS has a lifetime of four hours per refill. After four hours of use, the PLSS O_2, H_2O and LiOH supply must be replenished, and the battery recharged. The LEM crew provisions have apparently excluded spare PLSS batteries. The LiOH supplied however, is adequate for approximately 24 hours of PLSS use.

The LEM waste management section consists of a 7/32 inch diameter hose (inside the cabin) which is attached to a bulkhead valve and an external 1/4 inch diameter tube. This leads to an overboard discharge, located between stages, in the engine exhaust area of the descent stage. In addition to this equipment, in-suit waste management devices have been included for removal of vomitus, urine, feces and flatus decontamination.

The LEM restraint assembly consists of suspended harness arm restraints, waist positioned pulley reel assemblies, head restraints and feet anchorage devices. Two such systems are provided; one at each flight station. The astronauts are restrained in an upright position for accomplishing their required tasks.

The internal LEM configuration includes a forward crew compartment (92 inch diameter cylinder, 40 inches long) and a midsection. The LEM crew stations are located in the forward crew compartment. Controls and displays are mounted directly in front of and to the outboard side of the astronauts. Two triangular windows (one for each crewman) are provided. The field of view through these windows is shown on Figure 9-5.

Dehydrated food has been provided in pliable plastic packages. Water is mixed with the food until the desired consistency is obtained. Using the food adapter valve, the crewman may eat with the space suit pressurized.

The LEM crew provisions weight is shown in Table 9-3.

TABLE 9-3 CREW PROVISIONS SUBSYSTEM WEIGHTS*

CREW PROVISIONS SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
CREW PROVISIONS	(190.6)	(5.0)	(394.9)	(5.0)	(429.9)	(5.0)
CREW ACCESSORIES	(84.0)		(139.5)		(139.5)	
Space Suits			36.0		36.0	
Portable Life Supt Syst.			52.5		52.5	
Radiation Dosimeter			2.0		2.0	
Suit Mtd. Comm. Telemetry			1.0		1.0	
Bioinstrumentation			3.0		3.0	
Thermal Coverall	15.0		7.5		7.5	
Lunar Boots	4.0		2.0		2.0	
Meteoroid Protect. Garment	60.0		30.0		30.0	
Supplementary Visors	1.0		.5		.5	
Thermal Gloves	3.0		1.5		1.5	
Emergency Oxygen Syst.			3.0		3.0	
PLSS Spare Parts	1.0		.5		.5	
CREW RESTRAINTS	(35.0)		10.0		(45.0)	
LIGHTING *	(20.5)	(5.0)	(20.5)	(5.0)	(20.5)	(5.0)
Landing		5.0		5.0		5.0
Internal	2.5		2.5		2.5	
External	18.0		18.0		18.0	

* Panel lighting (4#) is under controls and Displays.

TABLE 9-3 CREW PROVISIONS SUBSYSTEM WEIGHTS (cont'd)*

CREW PROVISIONS SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
SUSTENANCE & ASSOC. EQUIP.	(36.1)		172.9		(172.9)	
Water Probe**	.5		.5		.5	
Food Packaging &						
Disinfectant	9.2		94.9		94.9	
Medical Equipment			5.0		5.0	
LiOH Cartridge-PLSS	26.4		72.5		72.5	
WASTE MANAGEMENT	(15.0)		(15.0)		(15.0)	
EMERGENCY EQUIPMENT			(10.0)		(10.0)	
(Fire control, Leak Repair Kit, Dis-						
tress Signals)						
MISCELLANEOUS			(17.0)		(17.0)	
(Maps, Log Books, Tool Set)						
PERSONAL HYGIENE			(5.0)		(5.0)	
(Dentifrice, Razor, Cleaning &						
Deodorant Pads)						
FOOD PREPARATION & UTENSILS			(5.0)		(5.0)	
Total Crew Prov. - Inert	(164.2)		(185.5)		(220.5)	
Total Crew Prov. - Expendables	(31.4)	(5.0)	(209.4)	(5.0)	(209.4)	(5.0)
** Drinking water is under ECS code.						

[redacted]

9.3.2 LEM SHELTER

Due to the longer duration and increased level of activity of the LEM/S mission some additions and changes are required to the LEM crew provisions.

All LEM life support expendables such as oxygen, lithium hydroxide, activated charcoal, food and water are inadequate for the LEM/S mission. To determine the additional life support expendables required, an activity level corresponding to a metabolic heat output of 575 BTU/man-hr was assumed. The resulting weight of expendables required daily is listed in Table 9-4. Additional information is given in Appendix A.

As previously mentioned, the LEM crewmen wear their space suits with open face plates while in the cabin. During this time they are connected to the suit recirculating assembly via an umbilical. Constant wear of the space suits is desirable for LEM/S crew safety. In the event of sudden decompression of the cabin, due to structural failure or micrometeoroid penetration, the crewmen need only close their face plates and pressurize their space suits via the suit recirculating assembly and umbilical. Also, the available free volume in the existing LEM is not adequate to allow both men to don their space suits in an emergency.

There are indications however, that wearing an unpressurized space suit for periods in excess of six to eight hours may result in blisters and abrasions due to chafing of the skin. Also, wetting of the skin, due to failure of the suit recirculating assembly to remove all of the perspiration formed, and the collection of residue from dried perspiration may result in other dermatological problems.

A possible solution to the problem of constant space suit wear versus intermittent wear is to have at least one crewman in a space suit at all times, and both crewmen in space suits during the work day and while sleeping. This would reduce the risk of losing both crewmen in the event of sudden decompression, and would also allow each man to attend to his personal hygienic needs.

Due to the limited free volume and floor space available it may be advantageous to have both crewmen stand while engaged in tasks inside the shelter. Standing does not appear to be a strenuous activity under conditions of lunar gravity.

TABLE 9-4

TOTAL LEM/S
EXPENDABLES USAGE RATES (2 MEN)

ITEM	DAILY REQM'T (lbs)	REMARKS
OXYGEN	(22. 1)	Total Weight Listed Under EPS.
METABOLIC	4. 5	
LEAKAGE	5. 0	
REPRESSURIZATION	12. 6*	
LiOH	(9. 2)	Includes Activated Charcoal
ECS	4. 0	Total Weight Listed Under ECS.
PLSS	5. 2	Total Weight Listed Under Crew Provisions (Two, 4 hour sorties)
WATER	(39. 4)	
DRINKING & HYGIENE	20. 0	This water may be recycled for cooling use.
PLSS	19. 4	Lost from ECS Heat Transport Sect. & Total Weight listed under ECS.
FOOD, PACKAGING & DISINFECTANT	(4. 5)	Total weight listed under crew Provisions

* The repressurization value of 12. 6 pounds is based upon three refills of the LEM/S cabin each day (4. 2 lbs. O_2 for each refill). This oxygen requirement may be alleviated with the use of a storage container as discussed in Section 9. 6. 2.

A critical free volume parameter for 2 man lunar shelters or vehicles will be to allow adequate room for the crewmen while standing in full extravehicular garb with the vehicle open to the lunar vacuum.

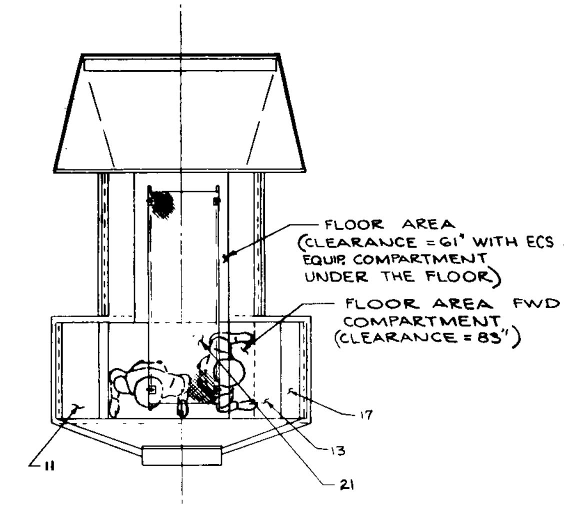
The existing LEM provides approximately 16 ft^2 of free floor space wherein a crew member may stand erect. This area is in the forward crew compartment. Figure 9-1 shows the internal arrangement for the LEM/S using the existing LEM structure. An alternate concept is shown in Figure 9-2. This concept utilizes a modified LEM structure which permits lowering of the midsection floor. The available floor space for standing erect was increased to 26 ft^2. The significance of the required structural modification for Concept II will be discussed in Section 9.12.1.

No usable data was available which relates human efficiency versus free floor area and time. However, the decrease in astronaut efficiency during the 14 day LEM/S mission, due to the restricted free floor area available for standing erect, may prove to be significant.

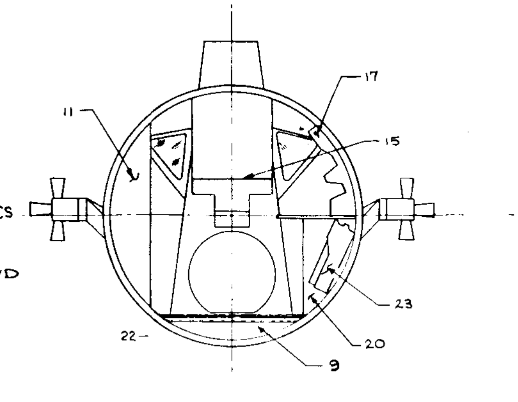
The absence of an airlock (which allows one man to leave the vehicle while the second man remains under pressurization) jeopardizes the mission and places severe reliability and habitability requirements on the suit system. A collapsible airlock using the LEM hatch as the inner airlock door would relieve this critical design deficiency. Due to adherence to the minimum modification concept a rigid airlock was not added to the LEM/S. The collapsible airlock was not added due to the lack of information indicating the feasibility for use of existing material in this manner.

An alternate solution would utilize a storage container. To depressurize the cabin, the cabin oxygen would be pumped into a storage container until such time as cabin repressurization is required. This system will be discussed in more detail in Section 9. 6. 2, however it may be noted that the storage container system is lighter than the vented system for 26 or more cabin repressurization cycles.

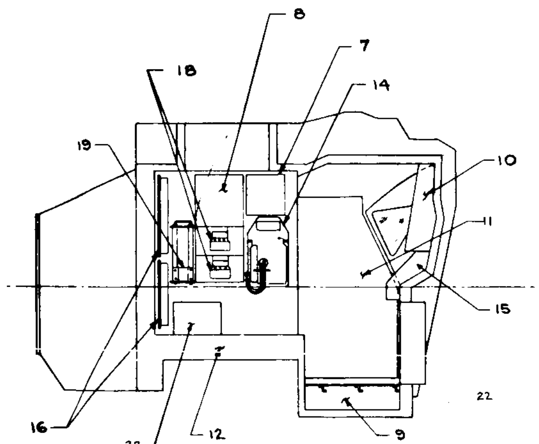
The LEM/S crew stations have been changed significantly from those of the LEM. All controls are located at the System Engineer's station and within a small area on the forward crew compartment bulkhead. A work table, spare SSA and PLSS and bunks have been added. The LEM/S crew station arrangement is shown in Figure 9-3.


FLOOR AREA
(CLEARANCE = 61" WITH ECS
EQUIP. COMPARTMENT
UNDER THE FLOOR)
FLOOR AREA FWD
COMPARTMENT
(CLEARANCE = 83")
17
13
21
11

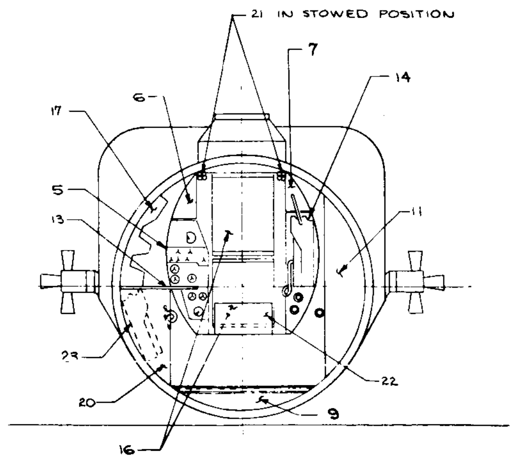
F — F


17
11
15
23
20
22
9

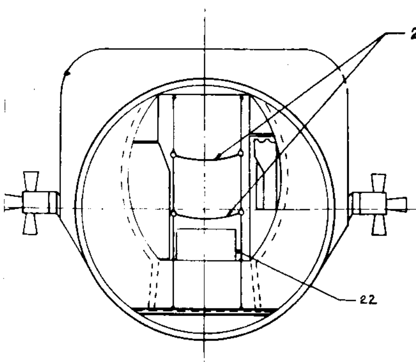
D — D


8
7
18
14
19
10
11
15
22
16
22
12
9

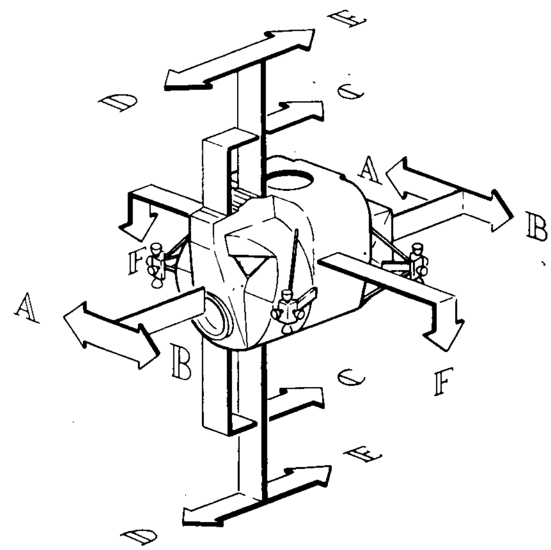
B — B


21 IN STOWED POSITION
7
14
6
17
5
11
13
23
22
20
9
16

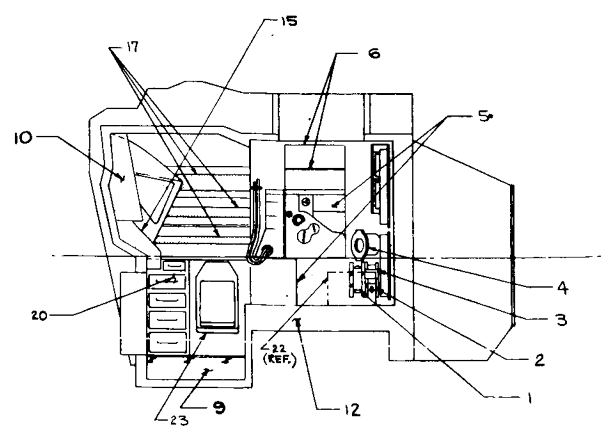
C — C



E = E



NO SCALE



A = A

23 SPARE PLSS BACK PACK
22 SPARE SPACE SUIT CONTAINER
21 COLLAPSIBLE BUNKS
20 SCIENTIFIC EQUIP. STORAGE
19 PLSS BATTERY CHARGER
18 SPECIMEN CONTAINERS
17 CONTROLS & DISPLAYS
16 POWER SERVO ASSY & ELECTRONIC COUPLING DISPLAY UNIT (PSA & ECDU)
15 CONTROLS & DISPLAYS
14 PLSS
13 WORK TABLE
12 STORAGE CONTAINER EQUIPMENT
11 STORAGE AREA, LiOH (ECS)
10 STORAGE AREA, LiOH (PLSS) & FIRST AID
9 FOOD STORAGE
8 FOOD STORAGE
7 FOOD STORAGE
6 FOOD STORAGE
5 ECS EQUIP.
4 LIOH CARTRIDGE STORAGE
3 AUTOMATIC PUMP SWITCH
2 COOLANT RECIRCULATION ASSY
1 REGENERATIVE HEAT EXCHANGER

FIGURE 9-1

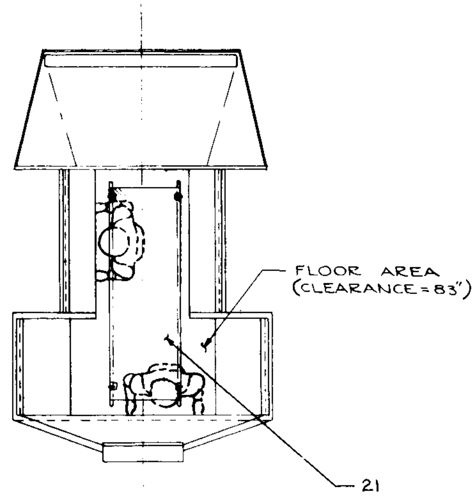
LIST OF MATERIAL

SEE ENGINEERING RECORDS

LEM SHELTER CONCEPT I INTERNAL ARRANGEMENT

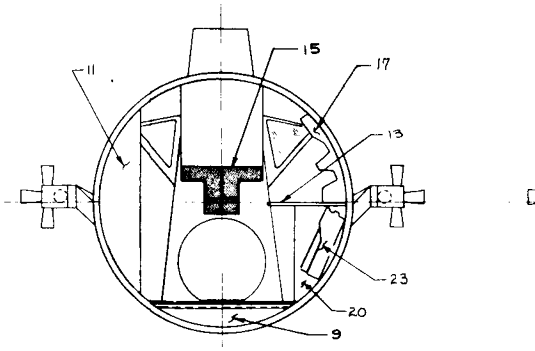
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-4



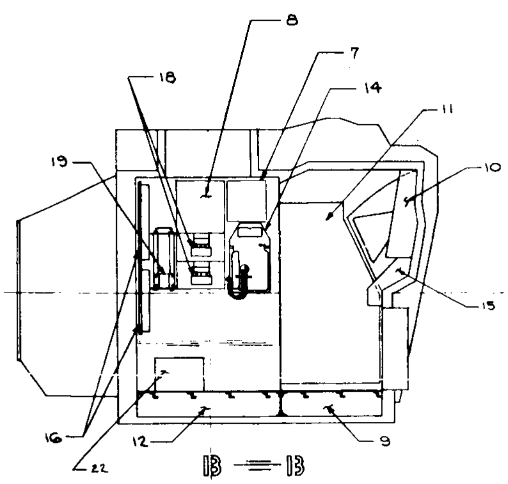
FLOOR AREA
(CLEARANCE = 83")
21

F — F



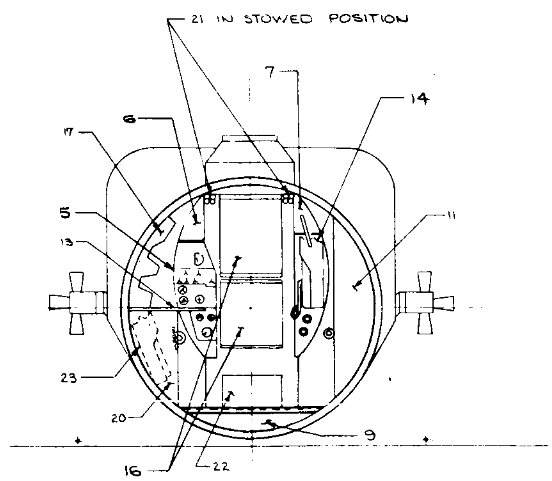
15
17
11
13
23
20
9

D — D



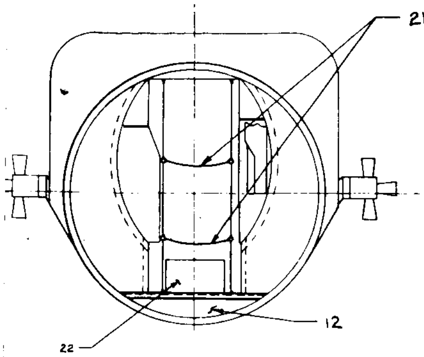
8
7
18
14
11
19
10
15
16
12
9
22

B — B

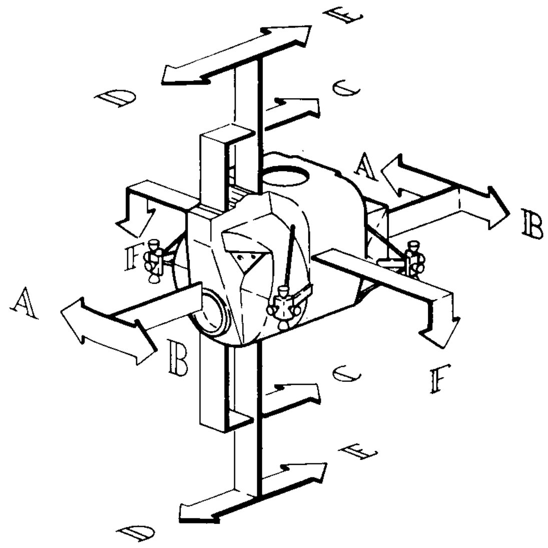


21 IN STOWED POSITION
7
14
17
6
5
13
11
23
20
9
16
22

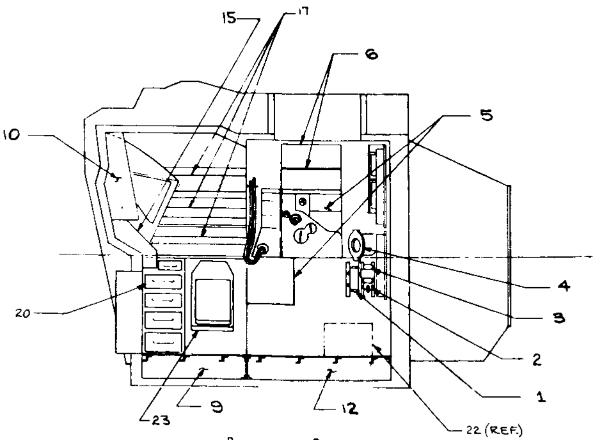
C — C



E — E



NO SCALE



A — A

23 SPARE PLSS BACK PACK
22 SPARE SPACE SUIT CONTAINER
21 COLLAPSIBLE BUNKS
20 SCIENTIFIC EQUIP. STORAGE
19 PLSS BATTERY CHARGER
18 SPECIMEN CONTAINERS
17 CONTROLS & DISPLAYS
16 POWER SERVO ASSY & ELECTRONIC COUPLING DISPLAY UNIT (PSA & ECDU)
15 CONTROLS & DISPLAYS
14 PLSS
13 WORK TABLE
12 STORAGE CONTAINER EQUIPMENT
11 STORAGE AREA, LiOH (ECS)
10 STORAGE AREA, LiOH (PLSS) & FIRST AID
9 FOOD STORAGE
8 FOOD STORAGE
7 FOOD STORAGE
6 FOOD STORAGE
5 ECS EQUIP.
4 LIOH CARTRIDGE STORAGE
3 AUTOMATIC PUMP SWITCH
2 COOLANT RECIRCULATION ASSY
1 REGENERATIVE HEAT EXCHANGER

FIGURE 9-2

LIST OF MATERIAL

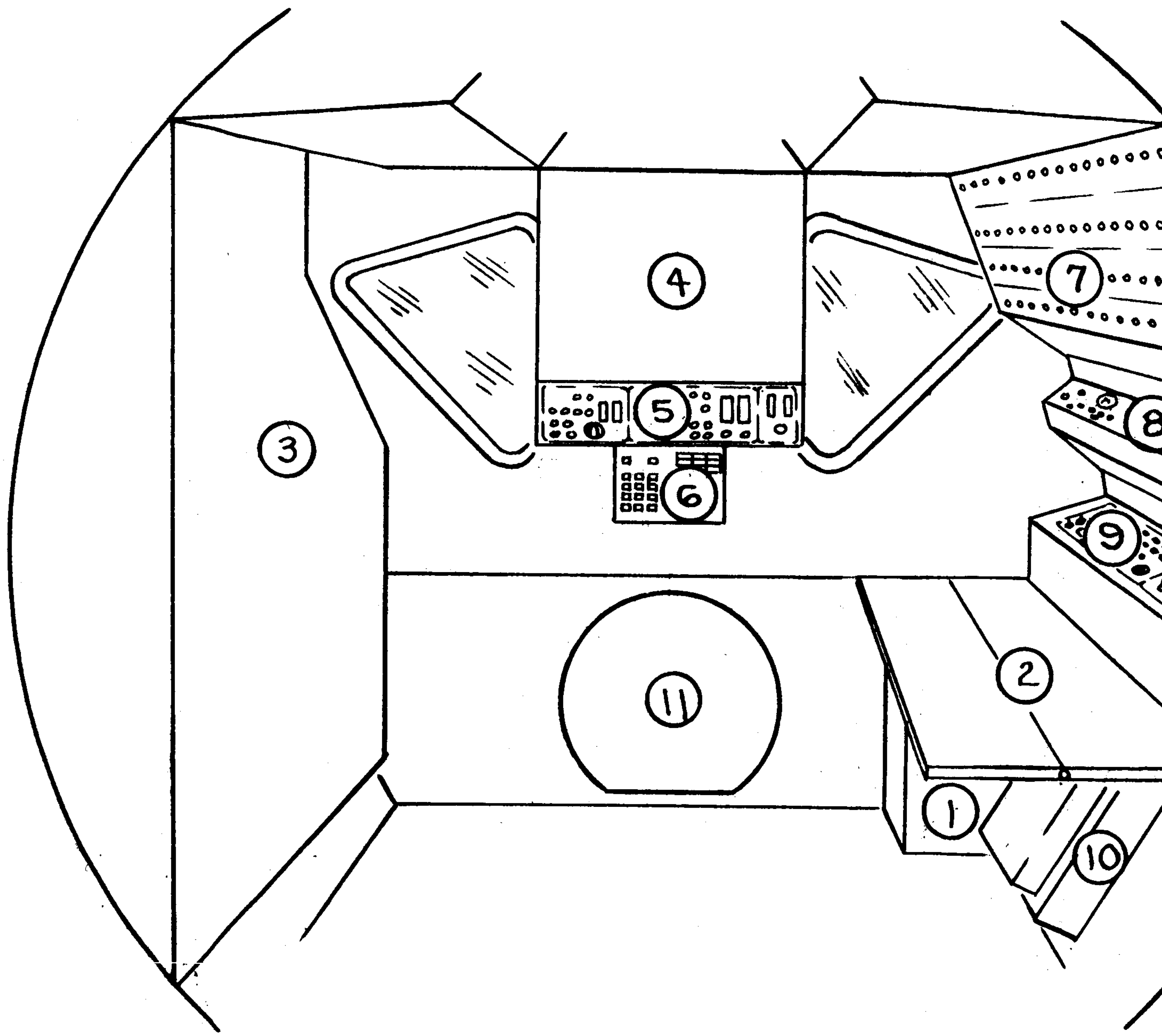
SEE ENGINEERING RECORDS

LEM SHELTER CONCEPT II INTERNAL ARRANGEMENT

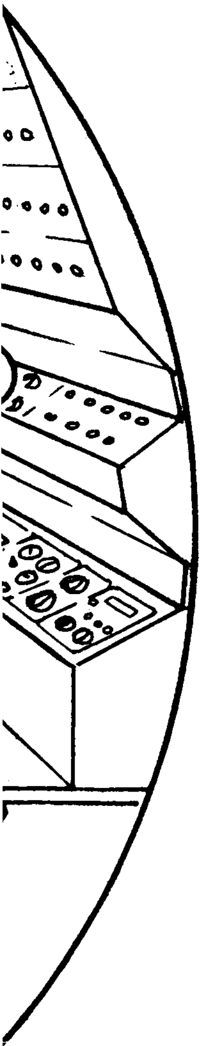
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-5

50



CREW STATIONS — CONTROLS & DISPLAYS
LEM/S CONCEPT



1. STORAGE FOR SCIENTIFIC EQUIPMENT

2. WORK TABLE

3. STORAGE FOR LiOH (ECS) AND MISCELLANEOUS EQUIP.

4. STORAGE FOR LiOH (PLSS) AND FIRST AID

5. CONTROL AND DISPLAY PANEL FOR LIGHTING, POWER GENERATOR AND CRYOGENIC STORAGE

6. CONTROL AND DISPLAY PANEL FOR ACTIVITY PROGRAMMER AND TELESCOPE

7. CONTROL AND DISPLAY PANEL FOR ENVIRONMENTAL CONTROL, COMMUNICATIONS, ELECTRIC POWER SYSTEM, INSTRUM., T. V., AND CRYOGENIC STORAGE

8. CONTROL AND DISPLAY PANEL FOR IMU CONTROL, RADAR AND PYROTECHNICS

9. CONTROL AND DISPLAY PANEL FOR AUDIO, COMMUNICATIONS, COMM. ANTENNAS, COAXIAL AND FEEDER CONTROL, N & GS

10. SPARE PLSS BACKPACK

11. FORWARD HATCH

FIGURE 9-3

The weights charged to the LEM/S crew provisions are shown in Table 9-3.

9.3.3 MOLEM

The same general requirements exist for the MOLEM and the LEM/S crew provisions excepting for accomplishing the mobility function. The internal arrangement drawing shown in Figure 9-4 indicates the location of the equipment and expendables carried inside the cabin enclosure.

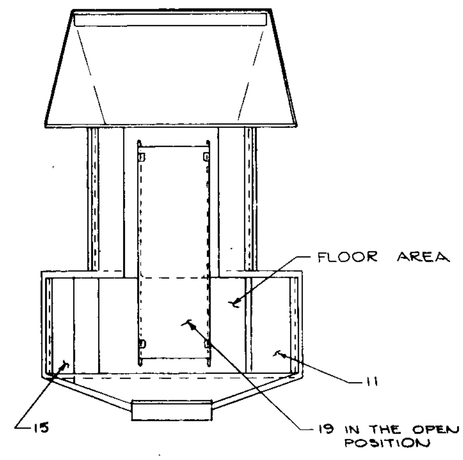
The visibility throught the forward windows from the LEM Commander's and System Engineer's design eye point is shown in Figure 9-5. As can be ascertained from this diagram, vision is inadequate from one station due to the restricted visibility. However, as is also shown in Figure 9-5, a buddy system of driving produces an excellent overlapping field of view with minimal blind spots. This system of driving is not recommended as a primary visual mode, rather a dual prism mirror system is recommended for exterior viewing when driving. The mirror system is illustrated in Figure 9-6. Additional information on other possible viewing systems such as fiberscopes, television, etc., is available in Reference 9. Other items shown in this Figure include the general layout of the crew driving and work stations. The crew member will use the existing LEM restraint harness while driving and the arm rests when convenient. The work table top is hinged to allow both members to be strapped in the existing LEM harness while driving, or allow one member to be seated at the work table. The weight of the MOLEM crew provisions is listed in Table 9-3.

No significant increase in internal volume was required to accommodate the mobility function. The resulting living volume is essentially the same as that shown for the LEM/S in Section 9.3.2. A mobility panel, Navigation and Guidance Control panel, locomotion control lever and a driving mirror system was added (Figure 9-6); otherwise the items required inside the cabin enclosure are the same as required for the LEM/S.

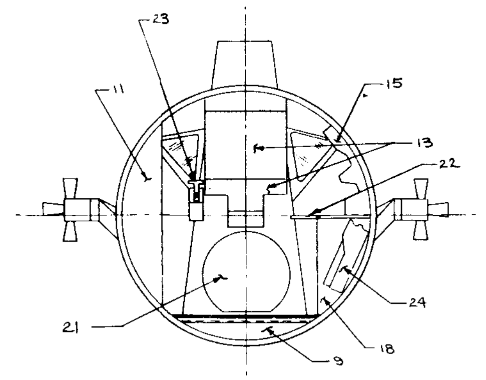
BLANK PAGE 54

4 3

D



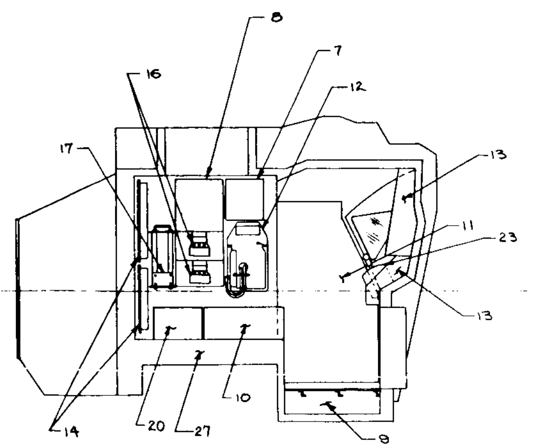
F — F



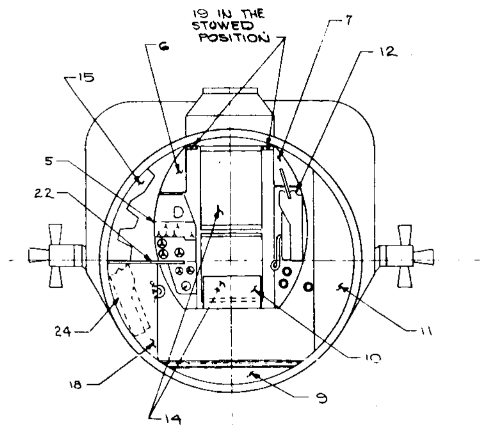
D — D

C

B



B — B

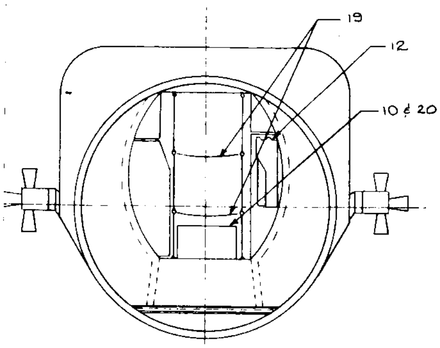


C — C

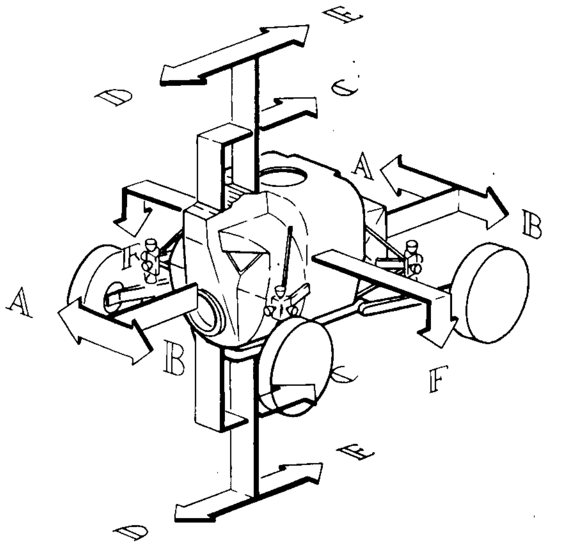
A

4 3

2 1

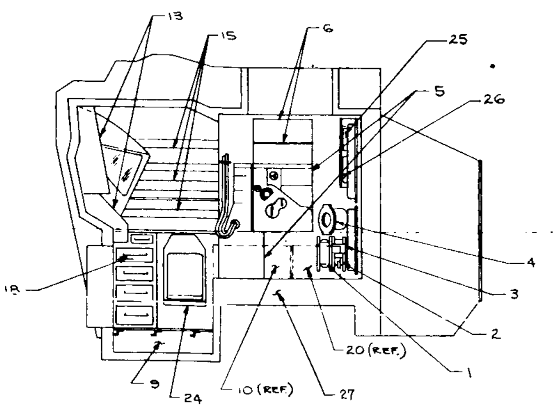


E — E



NO SCALE

27 STORAGE CONTAINER EQUIPMENT
26 RELAY BOX (ECS)
25 CABIN PRESSURE SWITCH (ECS)
24 SPARE PLSS BACK PACK
23 LOCOMOTION CONTROL LEVER
22 WORK TABLE
21 FORWARD HATCH
20 SPARE SPACE SUIT IN CONTAINER
19 COLLAPSIBLE BUNKS
18 SCIENTIFIC EQUIP. STORAGE
17 PLSS BATTERY CHARGER
16 SPECIMEN RETURN CONTAINERS
15 CONTROLS & DISPLAYS
14 POWER SERVO ASSY & ELECTRONIC COUPLING DISPLAY UNIT (PSA & ECDU)
13 CONTROLS & DISPLAYS - N & G, LOCOMOTION
12 PLSS
11 STORAGE AREA, LiOH (ECS) EMERGENCY EQUIP, PERSONAL HYGIENE, FOOD PREP. EQUIP. & MISC.
10 STORAGE AREA, LiOH (PLSS) & FIRST AID
9 FOOD STORAGE
8 FOOD STORAGE
7 FOOD STORAGE
6 FOOD STORAGE
5 ECS EQUIP.
4 LiOH CARTRIDGE STORAGE
3 AUTOMATIC PUMP SWITCH
2 COOLANT RECIRCULATION ASSY
1 REGENERATIVE HEAT EXCHANGER



A — A

FIGURE 9-4

LIST OF MATERIAL

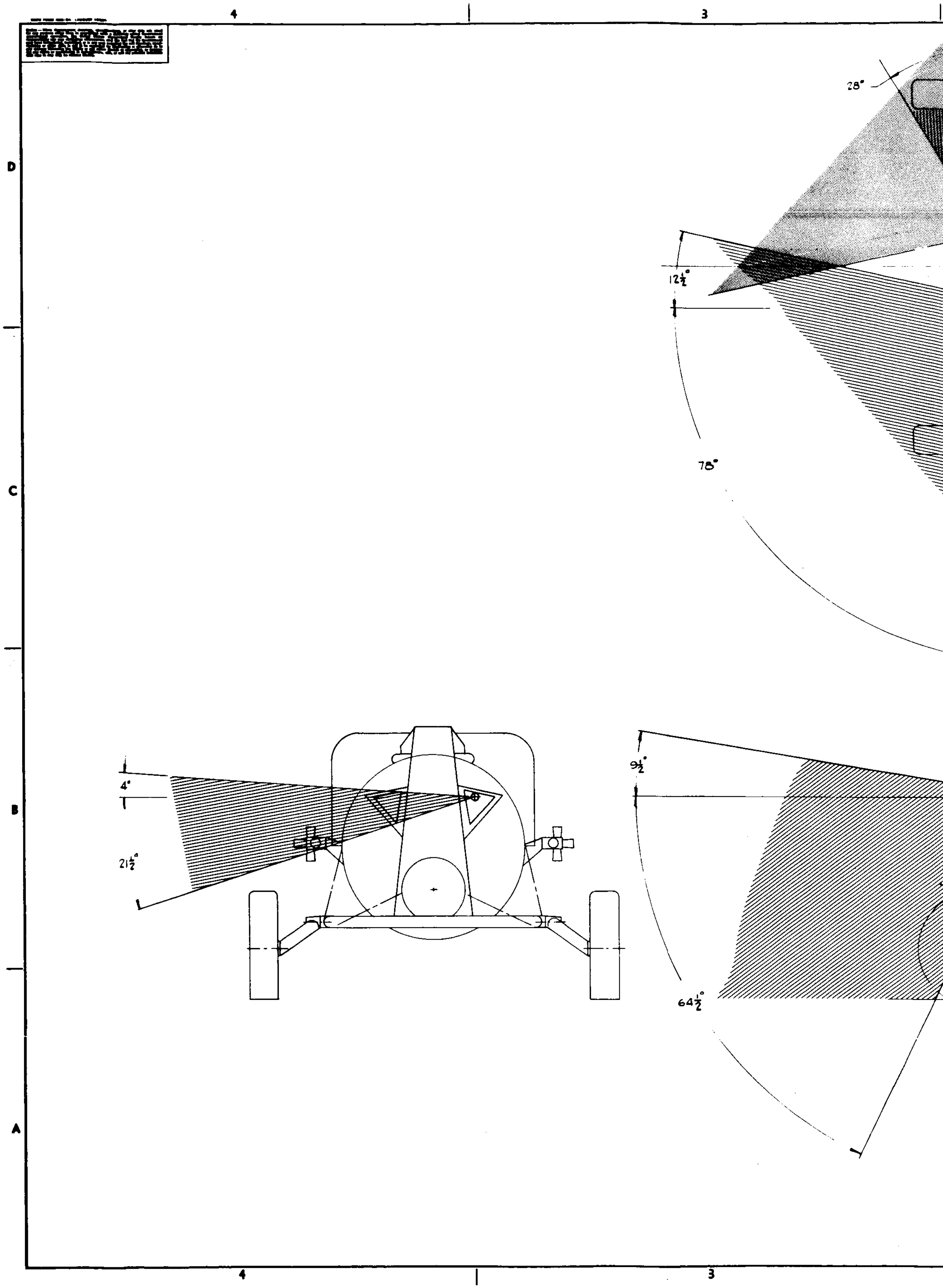
SEE ENGINEERING RECORDS

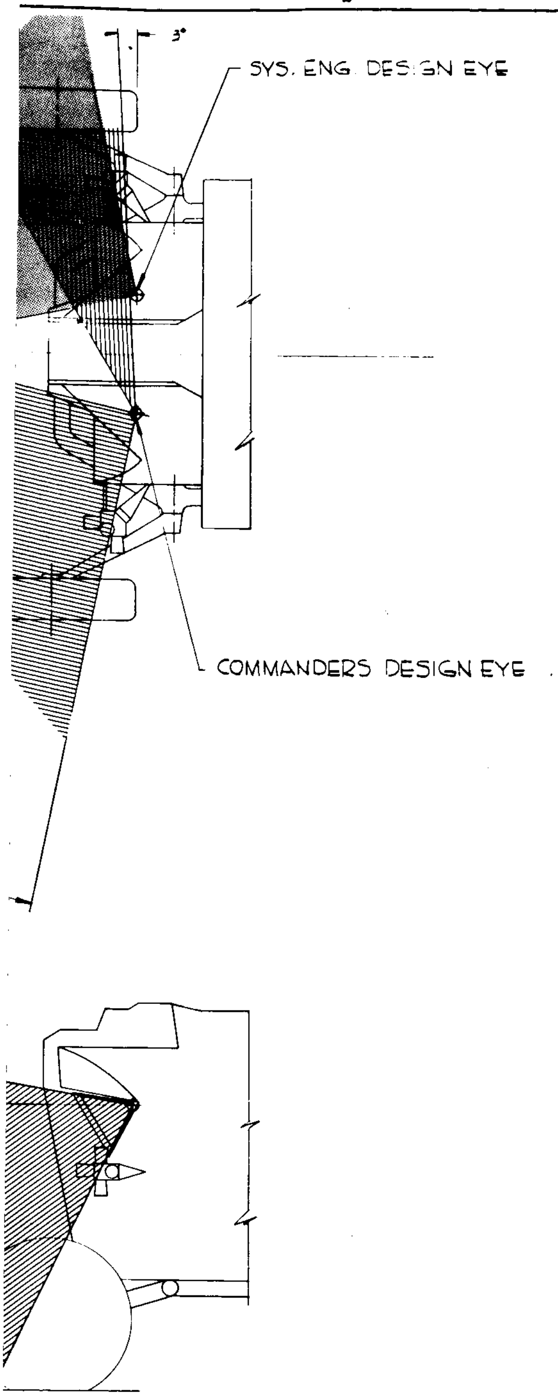
MOLEM
INTERNAL
ARRANGEMENT

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-6

SCALE 1/20


4
3
D
C
B
A
28°
12½°
78°
4°
21½°
9½°
64½°



COMMANDERS FIELD OF VISION

SYS. ENG. FIELD OF VISION (MIRROR IMAGE OF COMMANDERS VISION)

FIGURE 9-5

LIST OF MATERIAL

ORIGINAL DATE OF DRAWING 4 MAR 65

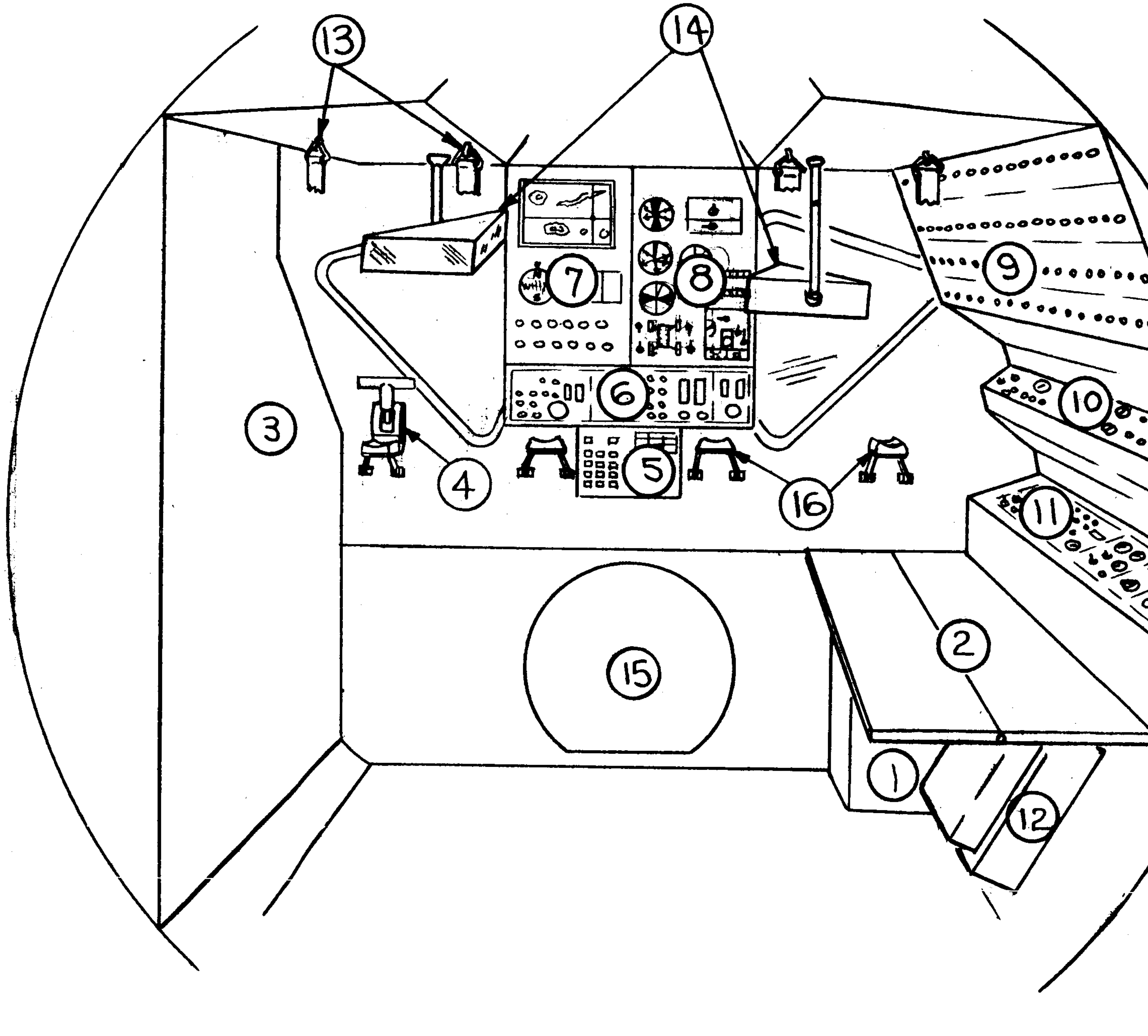
DED

EXTERIOR VISIBILITY DIAGRAM MOLEM CONCEPT

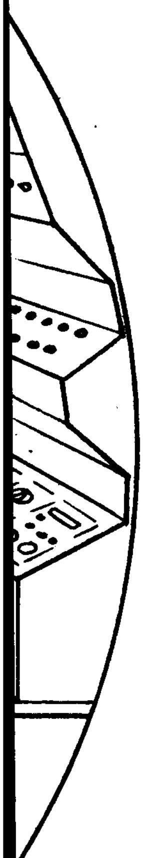
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-7

SCALE 1/20



CREW STATIONS -- CONTROLS & DISPLAYS
MOLEM CONCEPT



1. Storage for Scientific Equipment
2. Work Table
3. Storage Area for LiOH (ECS) Emergency Equipment, Personal Hygiene, Food Preparation Equipment and Miscellaneous
4. Locomotion Control Lever
5. Activity Programmer and Telescope Panel (This Item Presently Exists in LEM)
6. Displays for Lighting, Power Generator and Cryogenic Storage
7. Display Panel for Navigation and Guidance
8. Display Panel for Controls
9. Display Panel for Environmental Control, Communications, Electric Power System, Instrumentation, T.V. Cryogenic Storage
10. Display Panel for IMU Control, Radar, Pyrotechnics
11. Display Panel for Audio, Communications, Comm. Antennas, Coaxial and Feeder Control
12. Spare PLSS Backpack
13. Restraints While Driving (This Item Presently Exists In LEM)
14. Driving Mirror System
15. Forward Hatch (This Item Presently Exists in LEM)
16. Arm Rests (This Item Presently Exists in LEM)

FIGURE 9-6

9.4 ELECTRICAL POWER SUBSYSTEM

The EPS provides power to all electrical and electronic equipment aboard the LEM and its derivatives. The primary source of power considered was the hydrogen-oxygen fuel cell.

The power requirements and power systems for the LEM, LEM/S and MOLEM will be discussed in this section.

9.4.1 LEM

The LEM EPS consists of a Fuel Cell Assembly (FCA), a Cryogenic Storage and Supply Assembly, various controls, and an auxiliary battery. The FCA includes primarily three .9 kw open cycle fuel cells. Hydrogen and oxygen are supplied to the fuel cells from the Cryogenic Storage and Supply. Gaseous hydrogen and oxygen pass through porous nickel-nickel oxide electrodes and react with an aqueous potassium hydroxide electrolyte. This reaction causes the hydrogen and oxygen reactants to ionize, release electrons, and produce water. The heat generated by the fuel cell is removed by passing an excess of hydrogen through the hydrogen gas space. The excess hydrogen and the water produced by the fuel cell is vented overboard. Cooling the fuel cell in this manner eliminates the need for an EPS radiator.

For purposes of fuel cell studies the fuel cell oxidizer used on LEM was considered to exclude all oxygen used for metabolic needs, cabin repressurization, leakage requirements, all residual oxygen, and the oxygen used on descent and ascent. The fuel was similarly considered to be the hydrogen used on the lunar surface. The weight ratio of oxidizer to fuel used in the production of electric power is, from stoichiometry, 8:1. However, since hydrogen is also used for cooling in the LEM fuel cells , the ratio of oxidizer to fuel passing through the LEM fuel cells is approximately 2:1. This then indicates that the ratio of hydrogen used for cooling to hydrogen used for production of electrical energy is 3:1.

The three .9 kw fuel cells are started prior to earth launch and are operated at low power levels for the duration of the earth orbit, cislunar flight and lunar orbit. The fuel cell power requirements are increased near the time of separation of LEM from the CM/SM. Operation of the fuel cells over this time period results in the expenditure of approximately 36 lbs of cryogenic reactants.

In a parallel operating condition the fuel cells provide power to two essential buses and one monitor bus. For nonparallel operation each fuel cell provides power to one of the three buses. In the event a fuel cell fails, a logic network in the feeder control assembly deenergizes the monitor bus to allow the operating fuel cells to provide power to the essential buses.

Should all fuel cells fail, an auxiliary battery provides power to all critical survival circuits. This battery is capable of furnishing power to all critical circuits at any time during lunar launch, rendezvous and docking. The auxiliary battery can supply approximately 2.5 Kw-hrs of electrical energy.

The cryogenic storage and supply assembly consists of three liquid hydrogen (LH_2) tanks, two liquid oxygen (LOX) tanks and associated valves and piping. The liquid hydrogen and oxygen are stored supercritically in spherical tanks. Two LH_2 tank and one LOX tank are stored on the ascent stage while the others are stored on the descent stage. During descent and while on the lunar surface the descent stage cryogenic supply is used. The ascent stage cryogenic storage supply is used during ascent, rendezvous and docking.

The LEM EPS weights are given in Table 9-5.

TABLE 9-5 ELECTRICAL POWER SUBSYSTEM WEIGHTS*

ELECTRICAL POWER SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
ELECTRICAL POWER SUPPLY *	(956.2)	(355.8)	(2096.7)	(124.9)	(2521.3)	(124.9)
POWER GENERATION SECTION	(434.1)	(307.8)	(1574.6)		(1999.2)	
Fuel Cells	197.4		228.0		360	
Oxygen Tanks	9.1	31.5	73		86	
Hydrogen Tanks	45.0	79.2	168		223	
Oxygen **	22.2	138.7	645		776	
Hydrogen	18.1	32.6	88.0		116	
Radiator			30.0		80	
Auxiliary Battery System	53.0		53.0	76.9	53.0	76.9
Plumbing -O_2 Feed	10.4	5.4	10.4		10.4	
-H_2 Feed	21.0	6.5	21.0		21.0	
Pyrotechnic Batteries	7.0		7.0		7.0	
Battery Charger	3.2		3.2		3.2	
Electrical Control Assy.	47.7		47.7		63.6	
RTG			200		200	
POWER CONVERSION SECTION	(42.6)		(42.6)		(42.6)	
Inverters	35.2		35.2		35.2	
Control Unit	7.4		7.4		7.4	
DISTRIBUTION SECTION	(68.0)		(68.0)		(68.0)	
Distribution Boxes	8.0		8.0		8.0	
Circuit Breaker Panels	30.0		30.0		30.0	
Junction Boxes	10.0		10.0		10.0	
Relay Boxes	20.0		20.0		20.0	

TABLE 9-5 ELECTRICAL POWER SUBSYSTEM WEIGHTS (cont'd)*

ELECTRICAL POWER SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
ELECTRICAL PROVISIONS	(411.5)	(48.0)	(411.5)	(48.0)	(411.5)	(48.0)
Stabilization and Control	16.2		16.2		16.2	
Navigation and Guidance	97.0	2.5	97.0	2.5	97.0	2.5
Crew System	2.5		2.5		2.5	
Environmental Control	4.8		4.8		4.8	
Instrumentation	171.0	27.0	171.0	27.0	171.0	27.0
Electrical Power	71.4	15.0	71.4	15.0	71.4	15.0
Propulsion	19.0	3.5	19.0	3.5	19.0	3.5
Reaction Control	17.0		17.0		17.0	
Communications	7.9		7.9		7.9	
Controls and Displays	4.7		4.7		4.7	
Total EPS-Inert	(915.9)	(184.5)	(1363)		(1629.3)	
Total EPS- Expendables	(40.3)	(171.3)	(733)		(892)	

* Heat Exchangers and Glycol Plumbing are included under ECS

** Includes ECS O_2

~~CONFIDENTIAL~~

9.4.2 LEM Shelter - The assumed LEM/S power profile is shown in figure 9-7. The three .9 kw LEM fuel cells appear to be capable of providing sufficient power for the peak loads shown. Since the LEM/S requires more electrical energy than the LEM, additional cryogenic reactants must be supplied.

The fuel cell reactants required to extend the LEM open cycle fuel cell capability to satisfy the LEM/S power requirements were determined as follows:

- The reactant consumption rate for the generation of usable electrical energy was assumed to be .8 lbs/kw-hr.

- The total electrical energy required was 626 kw-hrs.

- The reactant weight for the generation of usable electricial power is;

$$WT._{RC} = .8(626) = 500 \text{ lbs.}$$

- The oxygen and hydrogen weight used for power generation based on the stoichiometric ratio of 8:1 is;

$$WT_{O_2} = \frac{8}{9}(500) = 445 \text{ lbs}$$

$$WT_{H_2} = \frac{1}{9}(500) = 55 \text{ lbs}$$

- The weight of hydrogen used in cooling the open cycle fuel cells is;

$$(WT_{H_2})_c = 3\ (55) = 165 \text{ lbs}$$

- The total reactant weight is;

WT. of O_2 =	445 lbs
WT. of H_2 = 55 + 165 =	220 lbs
TOTAL REACTANT WT.	665 lbs

- The total cryogenic system weight including tankage, required for use with the open cycle fuel cells for 200 days storage is:

O_2 System Wt. = 1.11(445) =	495 lbs
H_2 System Wt. = 4.68(220) =	1030 lbs
TOTAL SYSTEM WT.	1525 lbs

POWER PROFILE
FOR
LEM SHELTER
(Active Phase)

TOTAL ENERGY = 626 kw-hrs.
ACTIVE TIME ENERGY = 466 kw-hrs.

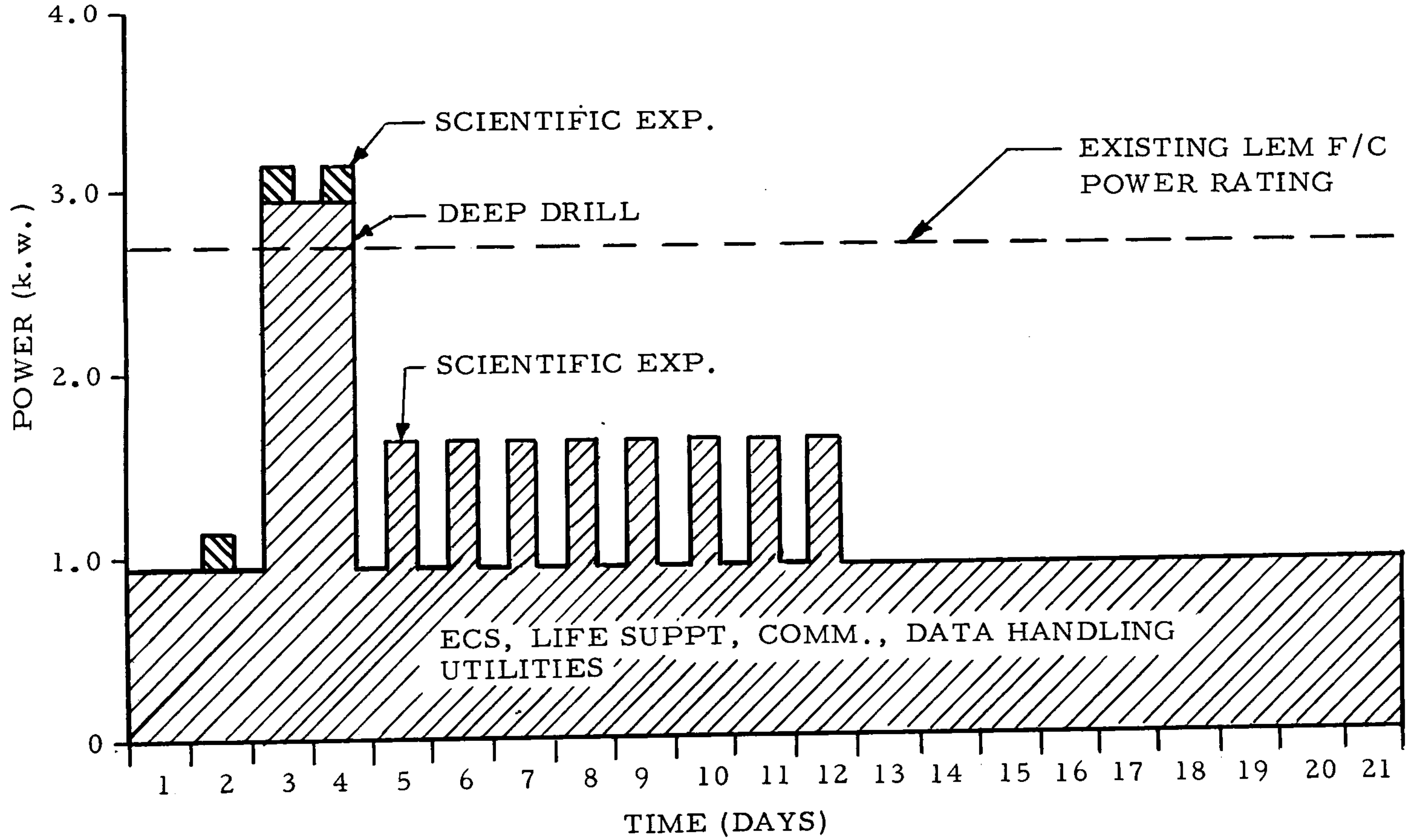


FIGURE 9-7

Obviously the weight penalty involved in using the existing LEM open cycle fuel cells is excessive. This weight penalty is even more substantial than indicated by the cryogenic storage requirement along.

The open cycle fuel cell discharges by-product water overboard, requiring that the entire supply of water for the ECS be carried from Earth. If the existing LEM ECS heat transport section were used, and astronaut activity on the lunar surface assumed to be 8 hrs. per day, the total ECS water requirement would be approximately 1860 pounds (see Section 9.6.2). Even if the LEM ECS were changed to include a 95 ft^2 radiator, the supplemental cooling and PLSS water requirement would be approximately 536 pounds. The two water requirements stated assume all drinking and wash water except urine are reclaimed for use in the heat transport section.

An alternate method of meeting the LEM/S power requirements would utilize a closed cycle fuel cell system. In this system the by-product water and a relatively small amount of excess hydrogen passed through the fuel cell are reclaimed, and cooling is accomplished by utilizing a secondary coolant and space radiator. The closed cycle fuel cell system is shown in Figure 9-8.

The approximate weight of the closed cycle system excluding fuel cells is as follows:

- The reactant weights as previously calculated are;

$$WT_{O_2} = \frac{8}{9}(500) = 445 \text{ lbs}$$

$$WT_{H_2} = \frac{1}{9}(500) = 55 \text{ lbs}$$

- The cryogenic system weight is;

$$O_2 \text{ SYSTEM WT.} = 1.11\,(445) = 495 \text{ lbs}$$

$$H_2 \text{ SYSTEM WT.} = 4.68\,(55) = \underline{256} \text{ lbs}$$

$$751 \text{ lbs}$$

- The radiator system weight, based on 35 ft^2 radiator, including plumbing, pumps etc., is;

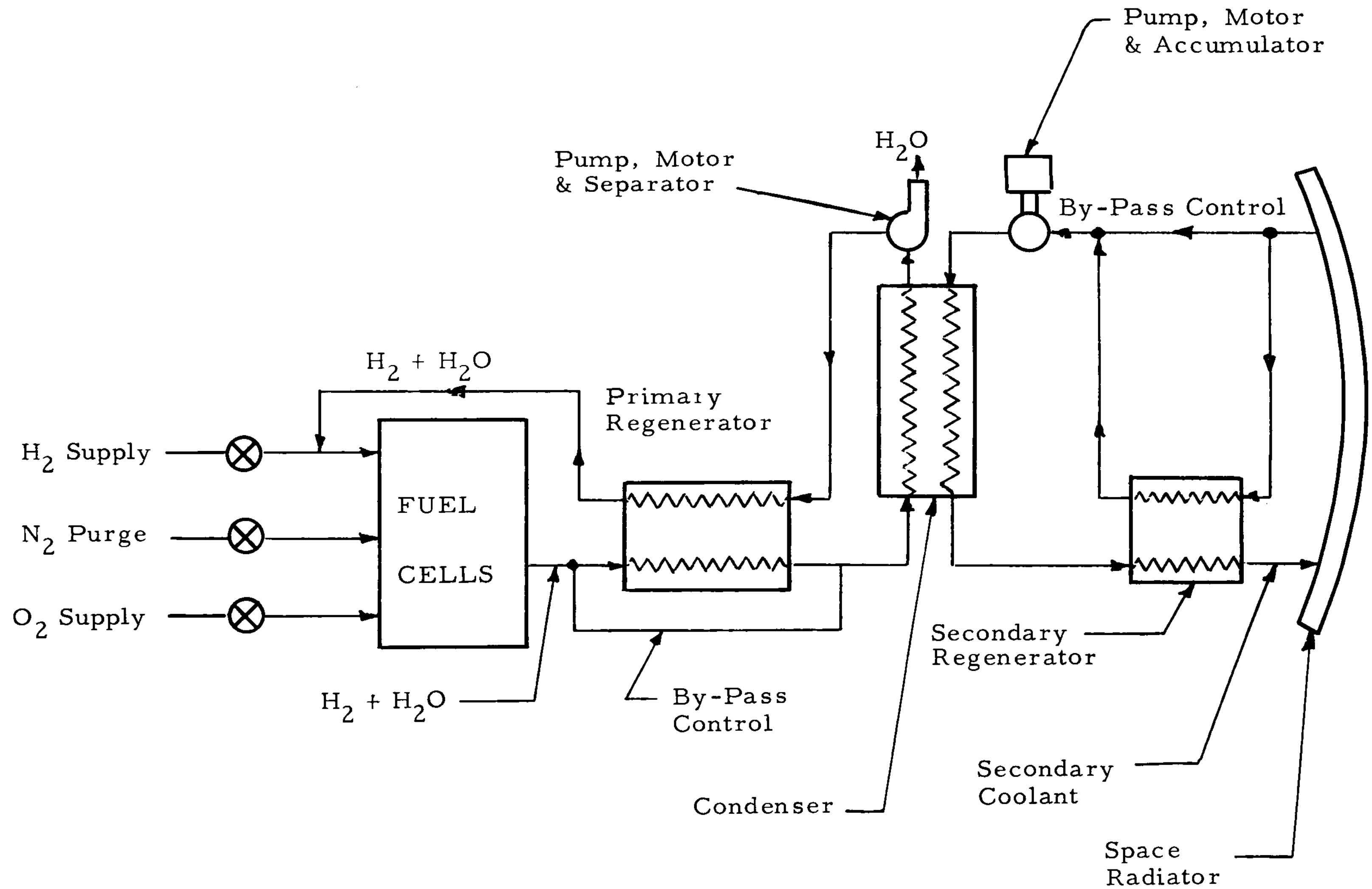
$$\text{RAD. SYSTEM WT} = 1.0 \frac{\text{lbs}}{\text{ft}^2}(35) = 35 \text{ lbs}$$

- The total system weight is;

REACTANT WT.	=	751 lbs.
RADIATOR WT.	=	35 lbs.
TOTAL WT.		786 lbs.

- Assuming an isomorphic conversion of fuel cell reactants to water, the water produced by the fuel cells is;

$$WT_{H_2O} = .8\,(626) = 500 \text{ lbs.}$$



CLOSED CYCLE FUEL CELL
SYSTEM SCHEMATIC

FIGURE 9-8

Table 9-6 summarizes the weight penalties associated with the open cycle and closed cycle fuel cells. This table indicates that a weight saving of 1239 pounds can be realized if the closed cycle fuel cell system utilizing a 35 ft^2 radiator is used for the LEM/S mission, in lieu of the open cycle fuel cell system.

TABLE 9-6

WEIGHTS ASSOCIATED WITH THE USE OF OPEN CYCLE AND CLOSED CYCLE FUEL CELLS FOR THE LEM/S MISSION

	Open Cycle	Closed Cycle	ΔWT(lbs)
Reactant sys. weight	1525	751	-774
Fuel Cell Radiator	0	35	35
Fuel Cell Water	0	500	
ECS Water Required (Included in Earth Launch Weights)	1860	1360	-500
TOTAL WEIGHT DIFFERENCE			1239

The fuel cells selected for the LEM/S application are two 1.56 kw cells of the type manufactured by the Pratt & Whitney Corporation. The weights for the fuel cells, the subcritically stored oxygen and hydrogen and the associated tankage were derived from a previous study study of a Lunar Surface Vehicle.[11]

The LEM/S secondary power requirements, supplied by RTGs and batteries, were based on the following:

- The fuel cells would not be activated until shortly before arrival of the astronauts.

- The LEM/S ECS heat transport section will be in operation during the six month dormant period to maintain equipment temperature limits, including fuel cells. The temperature profile for non operating equipment and the heating requirements will be discussed in Section 9.6.2.

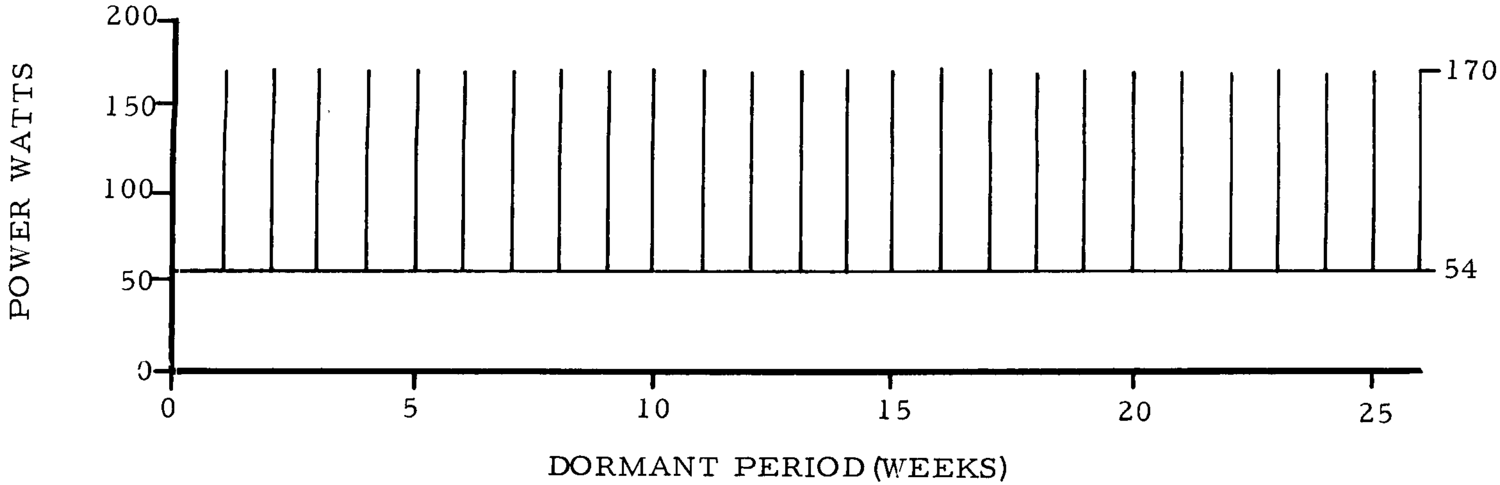
- Continuous monitoring and storing of lunar environmental data by LEM/S scientific equipment during 6 month dormant period.
- Weekly ten minute Manned Space Flight Network (MSFN) transmission of stored environmental data and subsystem status.
- Electrical power required for operational subsystems during descent to lunar surface.
- Emergency power.

The dormant phase power profile is shown in Figure 9-9. To meet the requirements of this profile, to provide adequate power for maintaining the fuel temperature at 70°F, and to provide power for fuel cell startup, four 50 watt RTGs have been included in the LEM/S secondary power supply. A one pound battery is provided to meet the peak power requirements shown in Figure 9. 9. To provide electrical power to operational subsystems used during descent to the lunar surface a 3. 6 kw-hr silver zinc battery was added. An emergency power supply, available at all times, is provided by the existing LEM 2. 5 kw-hr battery.

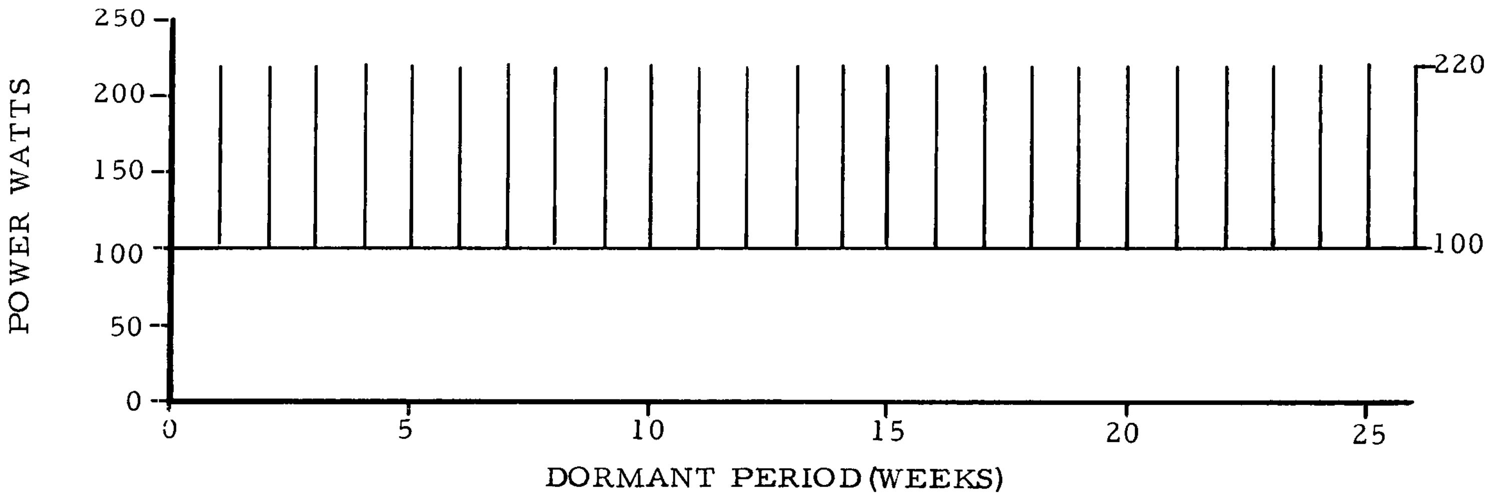
The LEM/S EPS is based on a cursory investigation and should in no way be construed as an optimum system. It is however, considered to represent a reasonable indication of the subsystem weights, and the problem areas with respect to conversion of the existing LEM to a LEM/S.

The cryogenic system weights previously given are based on two earlier studies [10, 11]. The hydrogen storage system weights reflect "minimum utilization of projected state-of-the-art advancements".[11] The hydrogen is subcritically stored in spherical tanks with a vent pressure of 50 psia. Five inches of superinsulation are used, and thirty-three pounds of hydrogen has been added for boil-off. The resulting LEM/S hydrogen tank is 56 inches in diameter. The ratio of total system weight to usable hydrogen weight is 4. 68[11].

The oxygen is subcritically stored in two spherical tanks with a vent pressure of 100 psia. The required power system oxygen weight was found to be 445 lbs. The required ECS oxygen weight is 200 lbs. The tank sizes were found to be 36 inches and 23. 5 inches in diameter respectively. The ratio of oxygen system weight to usable oxygen was found to be approximately 1.1[10]. This ratio was used for the EPS and ECS oxygen supply. The LEM/S EPS weights are given in Table 9-5. The oxygen weight given in Table 9-5 includes EPS and ECS oxygen requirements.



ELECTRONIC EQUIPMENT POWER REQUIREMENT



ECS POWER REQUIREMENT

POWER PROFILE DURING DORMANT PERIOD FOR LEM/S AND MOLEM

FIGURE 9-9

9.4.3 MOLEM

The power profile for the MOLEM scientific instrumentation is shown in Figure 9-10. The profile shows average and peak power requirements. The total energy requirement for this power profile is 124 kilowatt hours. Drilling is the most demanding power requirement for the scientific instrumentation, the 3rd and 4th days are devoted to a total time period of 42 hours for drilling a 10 meter hole. The 6th, 8th, 10th, 12th and 13th days shows the power required for drilling numerous 3 meter holes using the same drill used for deep drilling on the 3rd and 4th days.

The combined scientific instrumentation, mobility, ECS, Life Support Subsystem, Communications Subsystem and Data Handling power requirements vs mission time are shown in Figure 9-11. The total mobility energy requirement of 222.5 kw-hrs, is shown on Figure 9-11 and the peak power requirements are contained in Table C-1. As noted above, drilling operations occur on the 3rd, 4th, 6th, 8th, 10th, 12th and 13th days. Driving is not possible at the time of drilling since the drill rig will be mounted to MOLEM. The peak power required for the ECS, Life Support Subsystem, Communications Subsystem and for Data Handling is the same as the average power requirement. This then indicates that approximately 7.0 kilowatts of power is available for the steady state and acceleration phases of driving.

The existing LEM fuel cells cannot provide the required MOLEM power needs outlined in Figure 9-11. More LEM fuel cells could be added, (approximately six additional 0.9 kilowatts cells are required), making a total of nine cells with a combined power output of 8.1 kilowatts. However, since a change is already indicated, a more desirable solution is to use closed cycle fuel cells instead of the LEM open cycle cells. The reasons for preferring closed cycle to open cycle fuel cells have been well covered in Section 9.4.2 and will not be further elaborated upon.

The selected four, 2 kilowatt fuel cells were the type manufactured by Pratt and Whitney Aircraft Corporation. The weight, volume and operating characteristics were based upon a previous study of a Lunar Surface Vehicle[11]. The resulting weights for the fuel cells, subcritically stored oxygen and hydrogen and the associated tankage is shown in Table 9-5. The hydrogen weight includes an allowance for boil-off losses during the six month dormant period[11].

MOLEM POWER PROFILE
FOR SCIENTIFIC INSTRUMENTATION

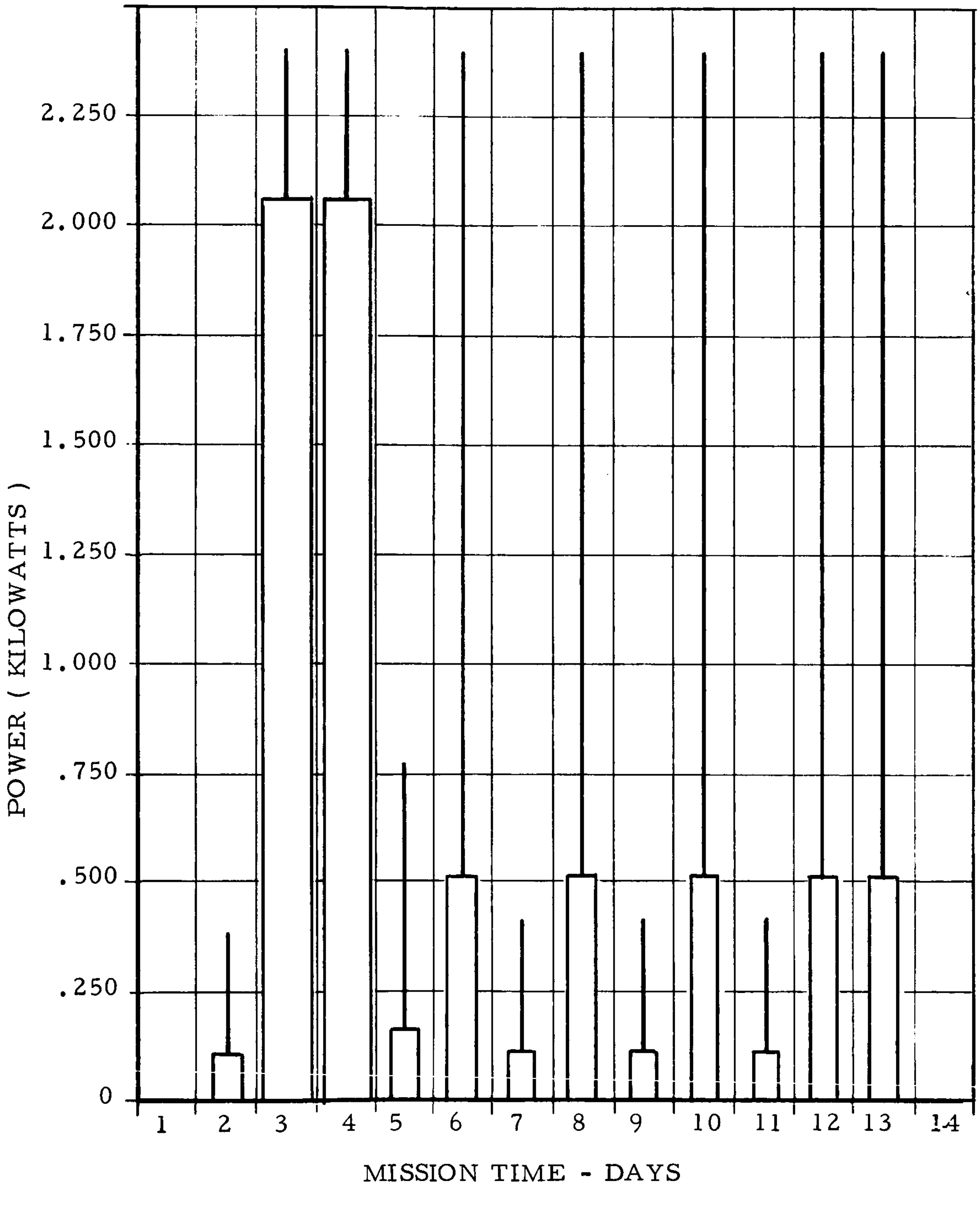


FIGURE 9-10

POWER PROFILE FOR MOLEM
(ACTIVE PHASE)

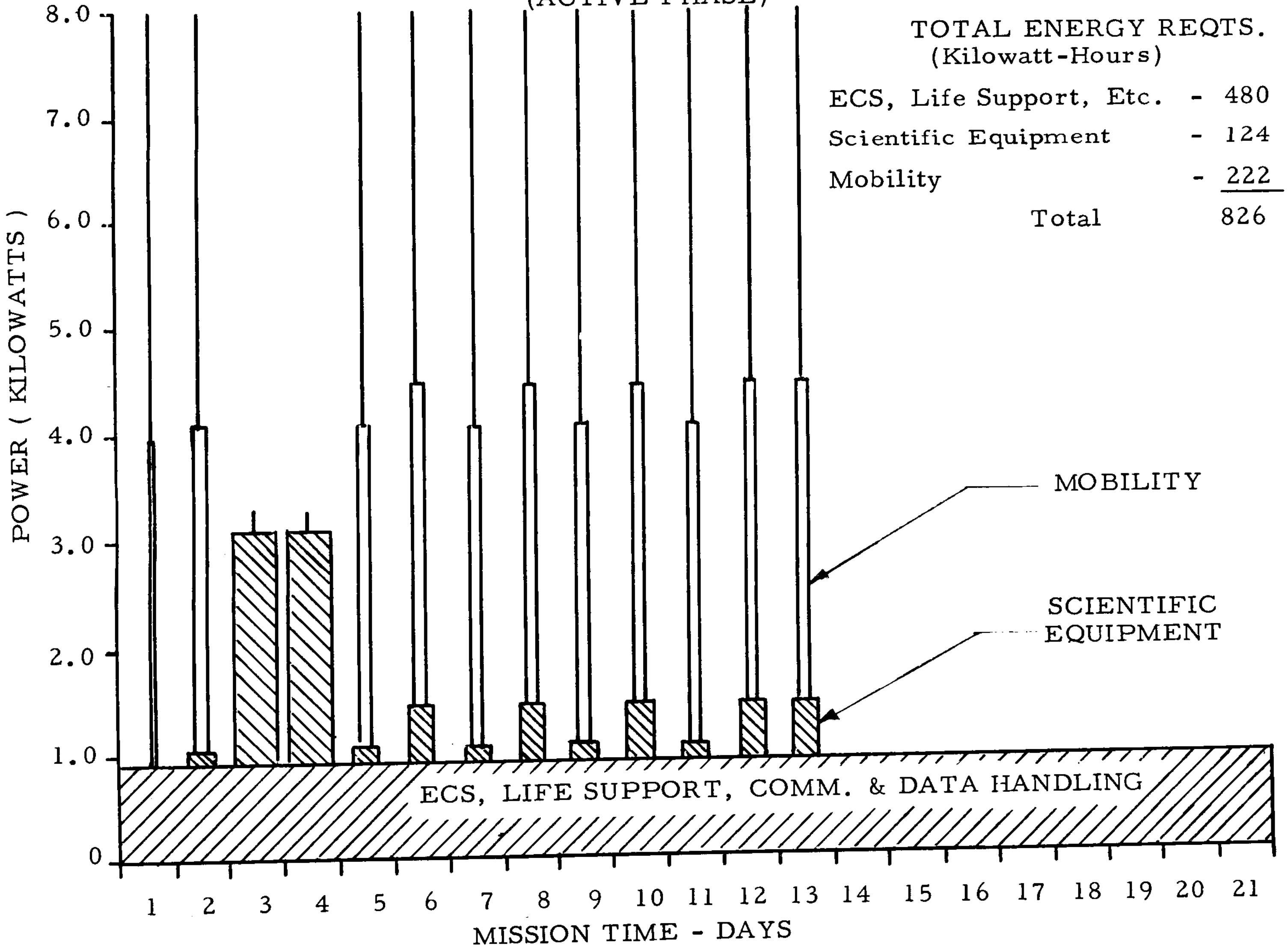


FIGURE 9-11

The secondary power requirements for the four 50 watt RTGs with a one pound battery for peak power requirements are unchanged from the needs of the LEM/S mentioned in Section 9.4.2 namely:

- Provide adequate power for the dormant phase power profile requirement of 154 watts average power and 390 watts peak power as shown in Figure 9-9.

- Provide power for fuel cell start-up. The cells will be maintained at 70°F during the dormant period utilizing insulation and electric heating. Approximately 200 watt-days will be required to reach the self starting temperature of 329°F. If heating is started 4 days before contemplated MOLEM usage, one 50 watt RTG has sufficient power to start up one fuel cell. A chain reaction could then be used to start up the remaining three cells.

During lunar descent, the same 3.6 kw-hr silver zinc battery is required for all of the operational subsystems as noted in Section 9.4.2. Finally, the existing LEM 53 pound auxilliary battery will be used as emergency power available at all times.

It is evident from a study of the proposed EPS that the power supplied by the RTG units during the dormant period can be utilized during the active mission phase. The use of this power will allow a saving in fuel cell reactants. This saving was not accounted for in this study because it required another iterative loop and additional task time. The weight saving including fuel and associated tankage is estimated to be 121 pounds.

The cryogenic storage system used for the LEM/S is also used for the MOLEM. The quantity of EPS oxygen and hydrogen has been increased due to the increased due to the increased power requirements. The oxygen is stored in two 30 inch outer diameter tanks each storing the same amount of oxygen , 388 pounds. The 116 pounds of hydrogen is stored in a 49 inch outer diameter tank. The oxygen weight given in Table 9-5 includes ECS oxygen. Table 9-5 lists the complete weight requirements for the MOLEM EPS.

9.5 INSTRUMENTATION SUBSYSTEM

The various instruments required by the three payload configurations being considered, will be discussed in this section. The instruments will be classified under two main categories, i.e., System Checkout Instrumentation (SCI) and Scientific Instrumentation (SI).

Systems Checkout Instrumentation senses physical data, monitors subsystems, provides status data for transmission, stores voice communications, etc. SCI is used to monitor functions within the spacecraft.

Scientific Instrumentation includes that equipment used to gather data, which may contribute to the advancement of scientific knowledge of space, or the moon.

9.5.1 LEM

Instrumentation aboard the LEM consists mainly of Systems Checkout Instrumentation. This includes such items as the Signal Conditioning Electronics Assembly (SCEA), Onboard Checkout Electronics Assembly (OBCEA), Caution and Warning Electronics Assembly (CWEA), Pulse Code Modulation and Timing Electronics Assembly (PCMTEA) and Data Storage Electronics Assembly (DSEA).

The SCEA gathers and conditions the various physical data (temperature, pressure, etc.) in the LEM subsystems. The data is modified for compatibility with the SCI.

The OBCEA provides checkout capability for LEM subsystems. This assembly includes logic circuitry for analyzing and testing subsystems, comparators and stored limits. Should a malfunction occur, the OBCEA is capable of isolating the particular item of equipment, subassembly or assembly, and providing visual display of subsystem status during checkout.

The CWEA furnishes the capability of rapid systems checkout during the manned mission phase. Audio and visual signals and displays have been provided to indicate any malfunction. To detect equipment malfunction the CWEA continuously monitors the SCEA.

The PCMTEA includes analog multiplexers, amplifiers, analog-to-digital converters, coders, digital multiplexers, digital registers, a programmer and a timing generator. The PCMTEA changes data into signals for transmission to Earth, and combines input data into a serial digital data train for presentation to Earth and the automatic checkout equipment.

The DSEA stores voice communications and time correlation by means of recording tape. No playback capability has been provided in the DSEA. All tapes are to be carried back to the CM/SM.

Scientific Instrumentation is carried aboard LEM for use on the lunar surface. The items of equipment included in the SI package, or the particular experiments to be conducted on the lunar surface by the LEM crew were undefined. However, a Scientific Instrumentation weight allocation exists for LEM.

The LEM instrumentation weights are given in Table 9-7.

9.5.2 LEM Shelter

Approximately 71 pounds of additional sensors were added to the existing systems checkout instrumentation aboard the LEM.

The LEM/S Scientific Instrumentation should be capable of furnishing information in the following areas;

- Environment
- Geology
- Biology
- Physiology
- Astronomy

To optimize the LEM/S Scientific Instrumentation system, the scientific equipment will be utilized in three separate modes. They are;

- LEM/S instrumentation
- Local Scientific Survey Module (LSSM) instrumentation
- Emplaced Scientific Station (ESS)

The LEM/S scientific instrumentation and equipment is shown in Table 9-8. Since the LEM/S does not incorporate a vacuum workshop, the vacuum experiments indicated may not be feasible. The feasibility of performing the vacuum experiments without the aid of a vacuum workshop is questionable, due to the use of reagents which may produce toxic fumes and relatively violent chemical reactions. The ECS may not be capable of removing the fumes produced.

A portable television camera is included in the LEM/S communications subsystem (Section 9.9.2) and this unit will serve for the instrumentation requirements also. The microwave and distance measuring device indicated may possibly be omitted. This function may be served by using the existing RR/T assembly.

The scientific instrumentation for use with the LSSM is given in Table 9-9. Due to the payload envelope constraints this equipment cannot be carried on the LSSM until the vehicle is unloaded from the descent stage. Therefore, provisions have been made for carrying the LSSM instrumentation in the descent stage for shipment to the moon.

The ESS instrumentation, listed in Table 9-10, must also be carried in the descent stage.

The LEM/S instrumentation weight is given in Table 9-7.

TABLE 9-7 INSTRUMENTATION SUBSYSTEM WEIGHTS*

INSTRUMENTATION SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
INSTRUMENTATION	(215.4)	(175.0)	(2070.7)	(655)	(1034.7)	(175.0)
OPERATIONAL	(150.7)		(150.7)		(150.7)	
Signal Conditioner	100.0		100.0		100.0	
PCMTE	47.0		47.0		47.0	
Data Storage Equipment	3.7		3.7		3.7	
IN-FLIGHT STATUS SYSTEM	(15.0)		(15.0)		(15.0)	
Caution and Warning Equipment	15.0		15.0		15.0	
SCIENTIFIC EQUIPMENT - GFE		(170.0)	(1784.0)	(650)	(738.0)	(170.0)
* Lunar Bound			1784	650	738.0	170.0
SENSORS	(49.7)	(5.0)	(121.0)	(5.0)	(131.0)	(5.0)
Structure		.1	10.0	.1	10.0	.1
Stabilization and Control	2.1		11.0		11.0	
Navigation and Guidance	4.0		10.0		10.0	
Environmental Control System	14.1	1.0	21.0	1.0	21.0	1.0
Instrumentation			2.0	.5	2.0	.5
Electrical Power System	10.5	.5	20.0		20.0	
Propulsion	10.7	3.4		3.4		3.4
Reaction Control System	7.7		21.0		21.0	
Communications	.6		6.0		6.0	
Cryogenic Storage			20.0		20.0	
Mobility					10.0	
* Includes LSSM						

TABLE 9-8

LEM SHELTER

SCIENTIFIC INSTRUMENTATION AND EQUIPMENT

Instrument or Equipment	Weight (kg)	Volume (cm^3)	Power (Watts)
Acoustic Type Ejecta Detector	0.5	16	.005
Total Radiation Dosimeter	0.1	1,000	0.1
Gamma Ray Detector (3 instr.)	0.8	1,008	.038
Surveying			
Microwave Distance Measuring Device	10	25,000	36
Theodolite	8	10,000	2
Rock Sampling	1	5,000	None
Camera	1	600	None
Camera (Television)	5	4,800	15
Drill	150	101,144	2,000
Borehole Logging (Recording Instrument)	5.8	8,590	7
Petrographic Analysis	12	15,575	200
X-Ray Analysis	10	13,268	60
Soil Analysis (Nest sieves, additional equipment listed under chemical analysis)	1	7,700	None
Chemical Analysis	5	10,000	None
Palynological Analysis	1	1,000	30
Vacuum Experiments	30	780,000	
Neutron Phoswich Spectrometer (1 instrument)	12.5	12,500	6.2
Telescope, NSL Modified Mount, and Accessory Equipment	31	9,800	1.0
Radio Astronomy, Instrumentation and Antenna Systems	29.8		12
Biological and Physiological Instrumentation	29	27,000	200
Total	343 (710 lbs)	1,034,001 (36 ft^3)	2,569

TABLE 9-9

LSSM
SCIENTIFIC INSTRUMENTATION AND EQUIPMENT

Instrument or Equipment	Weight (kg)	Volume or Dimensions	Power (Watts)
Magnetic Surveying			
Sensor and Electronics	2.5	1100	5
Cable	1	150	None
Gravity Surveying	15	15,625	22
Active Seismic Surveying	29.5	1950	48
Radioactive Surveying	2	1500	Self Contained
Field Geology	5.7	6145	Self Contained
Camera (For Field Geology)	2	1500	Self Contained
Camera (Sequential Photography)	5	6000	50
Camera, Television	5	4800	15
Surveying Equipment	10	25,000	36
Drill	60	22,388	1000
Borehole Logging Instruments	1.8	2890	449
Cone Penetrometer	0.6	180	None
Bevameter	5	16,000	100
Gas Chromatograph	6.3	2400	29
Total	151.4 (355 lbs)	107,628 cm^3 (3.76 ft^3)	1.754

TABLE 9-10

EMPLACED SCIENTIFIC STATION (ESS)
SCIENTIFIC INSTRUMENTATION AND EQUIPMENT

Instrument or Equipment	Weight (kg)	Volume or Dimensions	Power (Watts)
Meteoroid Ejecta Spectrometer	4	2025	0.4
Mass Spectrometer(two instruments)	6.5	8320	12
Charged Dust Spectrometer (two instruments)	4	800	1
Tidal Gravimeter	12	15625	25
Quake Seismometer	5	11000	7
Star Tracker	9	18200	16
Subsurface Temperature Probe	4	35000	0.5
Solar Plasma Spectrometers (two)	2.5	1000	1
Charged Particle Spectrometers (4 instruments)	3.0	4000	5
Neutron Phoswich Spectrometer	12.5	12500	6.3
Total Gas-Pressure Gage (2 instruments)	2	1250	12
Electric Field Meters (2 instruments)	4.5	1800	0.4
Hydrogen Lyman-Alpha Detector	3	3000	0.5
Magnetometer	2.5	1100	5
Communications			
Receiver and Antenna	2.3	2400	1
Transmitting System	7.8	5400	18
PCM/FM System	20.8	15112	270
Power Supply	30	9000	
Total	135.4 (297 lbs)	147,532 cm^3 (512 ft^3)	381

9.5.3 MOLEM

The existing LEM operational instrumentation was not changed excepting for 81.3 pounds of instrumentation sensors added to the MOLEM as shown in Table 9-7. A larger quantity of sensors was needed for all subsystems because of the longer duration MOLEM mission requirements.

Due to the limited payload capability of MOLEM, the Scientific Instrumentation was limited to the following discipline and general area of knowledge:

- Geology
- Lunar Environmental Data

Two modes of scientific instrumentation are employed:

- MOLEM instrumentation
- Emplaced Scientific Station (ESS)

The scientific instrumentation requirements proposed for the MOLEM are shown in Tables 9-10 and 9-11. The ESS requirements are the same as the LEM/S shown in Table 9-10. The TV cameras shown in Table 9-11 are in use on MOLEM for unloading purposes and are not, therefore, additional requirements.

The required 908 pounds of scientific instrumentation for MOLEM is carried on both stages; 170 pounds will be installed on the descent stage and 738 pounds on the ascent stage. The present scientific instrumentation bays on the descent stage are assumed adequate for the 170 pounds. The 738 pounds allocated for the ascent stage will be carried in the compartment formerly occupied by the LEM ascent stage engines.

The total weights for the MOLEM operational and scientific instrumentation are shown in Table 9-7.

TABLE 9-11

MOLEM

SCIENTIFIC INSTRUMENTATION AND EQUIPMENT

Instrument or Equipment	Weight (kg)	Volume or Dimensions (cm^3)	Power
Magnetic Surveying			
Sensor and Electronics	2.5	1,100	5
Cable	1	150	
Gravity Surveying	15	15,625	22
Active Seismic Surveying	29.5	1,950	48
Radioactive Surveying	2	1,500	Self Contained
Field Geology	6.7	6,145	Self Contained
Camera (For Field Geology)	2	1,500	Self Contained
Camera (Sequential Photography)	5	6,000	50
Cameras, Television (2)	10	9,600	30
Borehole Logging Instruments and recording instrument	7.6	11,480	456
Cone Penetrometer	0.6	180	None
Bevameter	5	16,000	100
Gas Chromatograph	6.3	2,400	29
Acoustic Type Ejecta Detector	0.5	16	.005
Total Radiation Dosimeter	.1	1,000	.01
Gamma Ray Detector (3 instr)	.8	1,008	.038
Surveying (under study)			
Camera (Laboratory)	1	600	None
Drill (30 meter)	150	101,144	2,000
Petrographic Analysis	12	15,575	200
X-Ray Analysis	10	13,268	60
Soil Analysis (Nest sieves, additional equipment listed under chemical analysis)	1	7,700	None
Chemical Analysis	5	10,000	None
Palynological Analysis	1	1,000	30
Neutron Phoswich Spectrometer	12.5	12,500	6.2
	287.1	272,241	3,036.3
	(631.6 lbs)	(9.6 ft^3)	

9.6 ENVIRONMENTAL CONTROL SUBSYSTEM

The ECS provides breathing oxygen, water, temperature and humidity control, and carbon dioxide and odor removal capabilities to the manned vehicle while operating in the hostile environment of space and the lunar surface.

The ECS used in the existing LEM will be described in this Section. The feasibility of using the LEM ECS in the LEM/S and MOLEM, and the necessary modifications will also be discussed.

9.6.1 LEM

The existing LEM Environmental Control Subsystem (ECS) consists of five (5) main sections, i. e., atmosphere revitalization, oxygen supply and cabin pressurization control, water management, heat transport and cold plate sections.

The atmosphere revitalization section provides the necessary requirements for revitalizing the atmosphere in the cabin and the space suits. Its function is ventilate and cool, monitor O_2 recirculation temperature, control the atmosphere carbon dioxide level, remove odors and noxious gases, remove excess moisture and provide control of gas temperature and flow throught the space suit and cabin.

The oxygen supply and cabin pressurization control section provides O_2 to the atmosphere revitalization section, additional O_2 for six cabin repressurizations and six Portable Life Support System (PLSS) refills. O_2 is also supplied at a rate equal to cabin leakage and crew consumption.

The O_2 supply section consists of two supercritical oxygen (SOX) tanks, a gaseous oxygen (GOX) accumulator and various valves and piping. One SOX tank and the GOX tank are aboard the ascent stage. The remaining SOX tank is aboard the descent stage.

The water management section provides water to meet the metabolic needs of the crew, vehicle cooling and two fills and four refills of the PLSS. The water management section consists of three water tanks, two in the ascent stage and one in the descent stage, pressure regulators, valves and piping.

The descent stage water supply furnishes water for all mission phases up to lunar launch. The water tanks are filled and pressurized prior to Earth launch. Additional water to satisfy the mission requirements is obtained by reclamation of water from the atmosphere revitalization section.

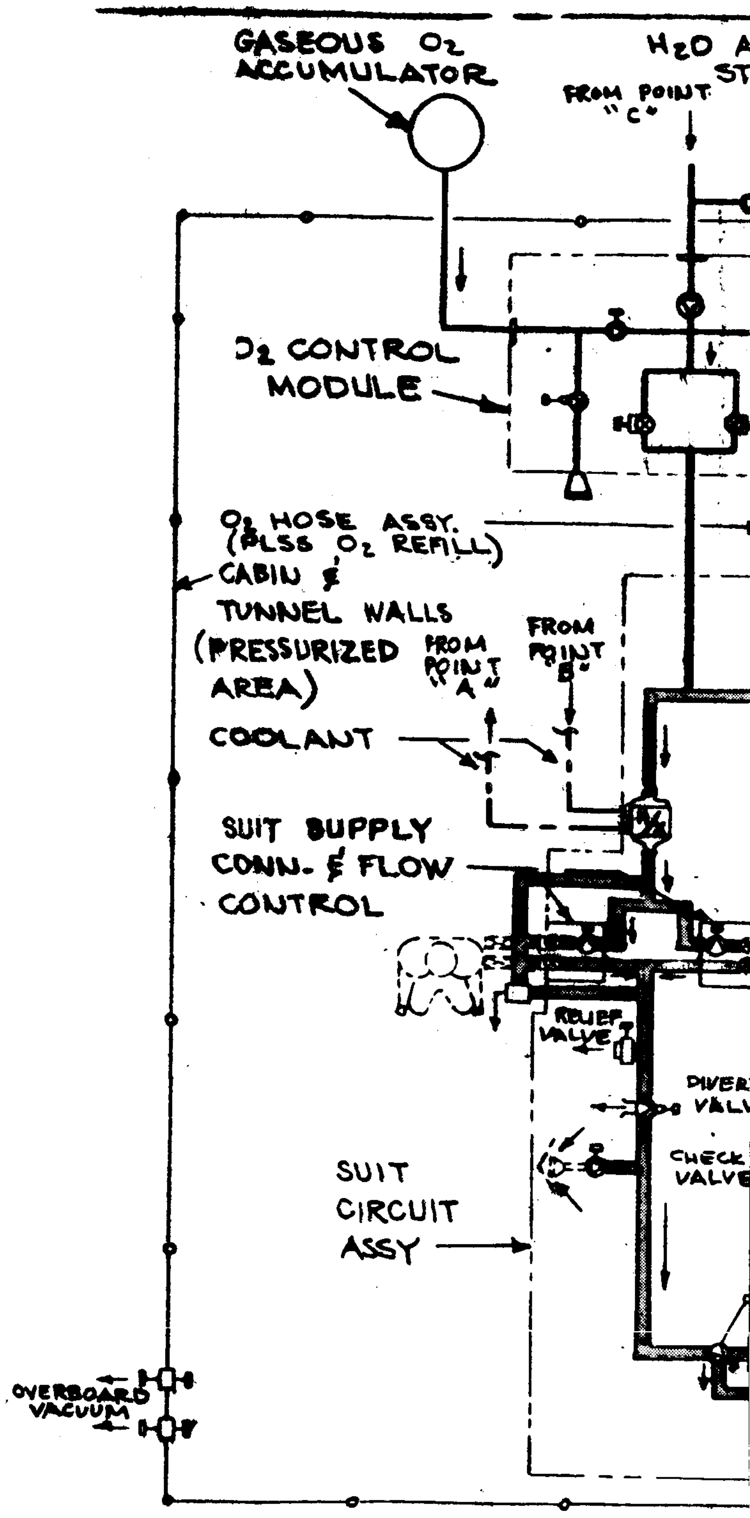
Two closed loop coolant systems are used in the LEM, i. e., a primary loop and a secondary loop. The two coolant loops circulate an ethylene glycol-water coolant fluid to provide the necessary thermal control for electronic equipment, cabin and space suits.

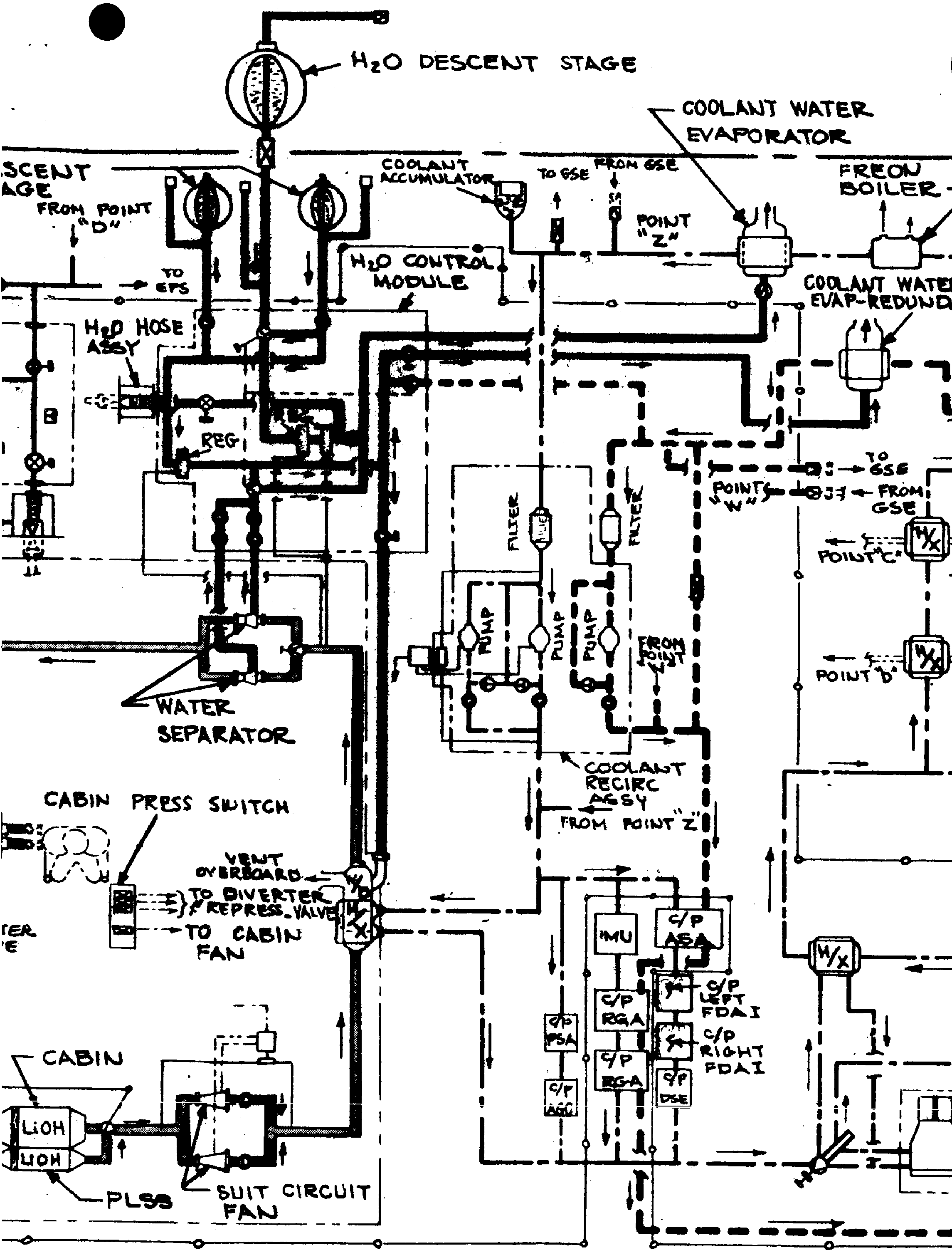
The primary coolant is circulated, by two pumps, through a cryogenic heat exchanger and then through the cold plate section. After accumulating heat from the cold plate section the coolant enters a coolant water evaporator. Water from the water management section is circulated around the coolant lines to remove heat. The water (in the form of steam) is then vented overboard. Simultaneously, primary coolant is circulated through a water separator in the atmosphere revitalization section to cool the coolant fluid and to vaporize moisture (which is vented overboard) in the recirculating oxygen. Also, further downstream, the recirculating oxygen line passes through a heat exchanger circulating primary coolant fluid. This heat exchanger warms the recirculating oxygen for use in the cabin, space suits and fuel cells.

The secondary coolant is circulated by one pump and provides cooling only to critical electronic components in much the same manner as the primary coolant. The coolant loops are shown on the LEM ECS schematic in Figure 9-12.

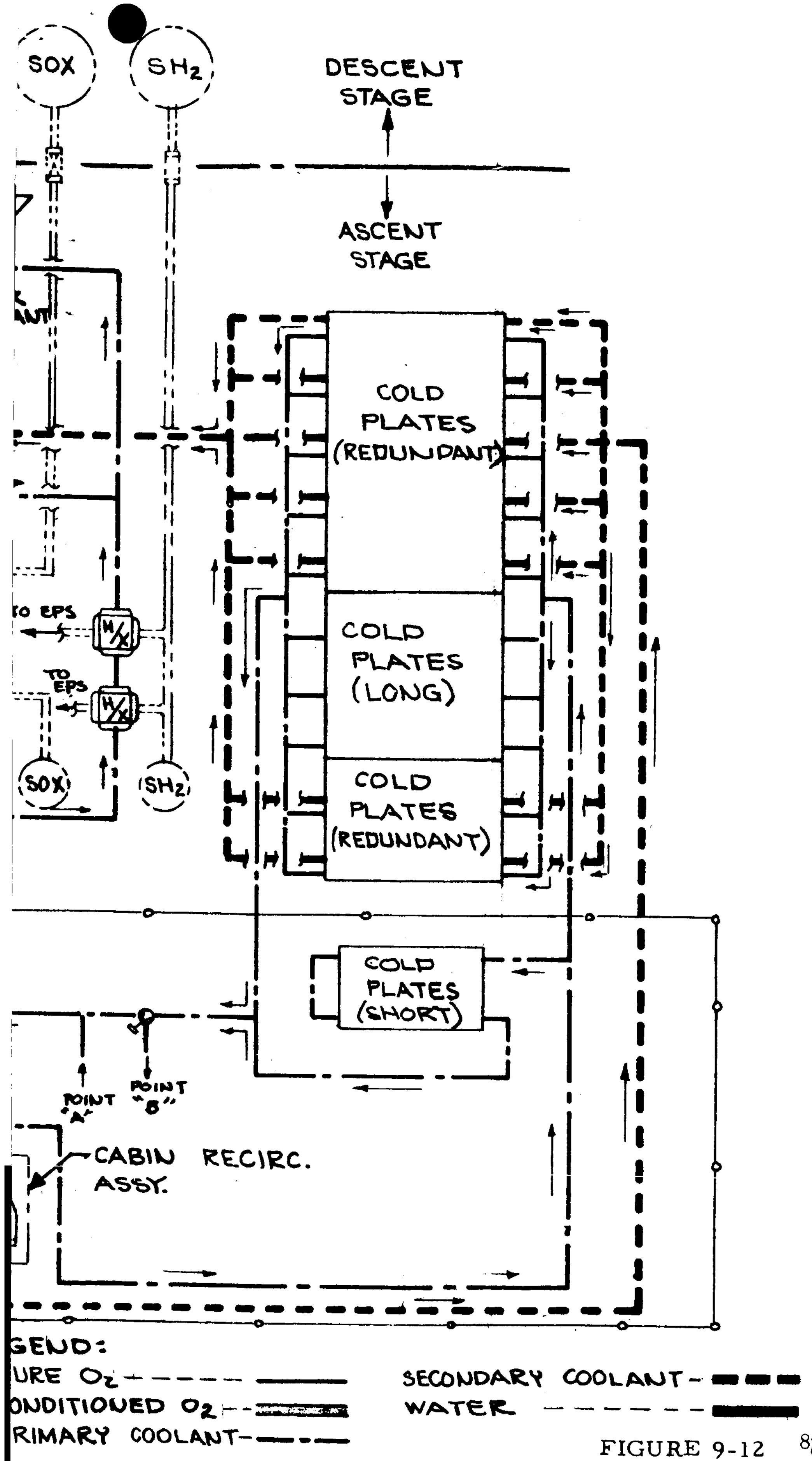
The cold plate section consists of several single pass heat exchangers. Electronic components requiring thermal control are attached to these cold plates.

The LEM ECS weight is given in Table 9-12.


GASEOUS O_2 ACCUMULATOR
H_2O A
ST
FROM POINT "C"
O_2 CONTROL MODULE
O_2 HOSE ASSY. (PLSS O_2 REFILL)
CABIN & TUNNEL WALLS (PRESSURIZED AREA)
FROM POINT "A"
FROM POINT "B"
COOLANT
SUIT SUPPLY CONN. & FLOW CONTROL
RELIEF VALVE
DIVER
VALV
CHECK VALVE
SUIT CIRCUIT ASSY
OVERBOARD VACUUM



LEM ENVIRONMENTAL CONTROL SYSTEM
SCHEMATIC
ABSTRACTED FROM REFERENCE 3



SOX
SH2
DESCENT STAGE
ASCENT STAGE
COLD PLATES (REDUNDANT)
COLD PLATES (LONG)
COLD PLATES (REDUNDANT)
COLD PLATES (SHORT)
TO EPS
TO EPS
H/X
H/X
SOX
SH2
POINT "A"
POINT "B"
CABIN RECIRC. ASSY.
GEND:
URE O2
ONDITIONED O2
RIMARY COOLANT
SECONDARY COOLANT
WATER

FIGURE 9-12

TABLE 9-12 ENVIRONMENTAL CONTROL SUBSYSTEM WEIGHTS*

ENVIRONMENTAL CONTROL SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
ENVIRONMENTAL CONTROL	(308.5)	(236.5)	(742.8)		(661.8)	
ATMOSPHERE REVITALIZATION SECT	(69.9)		(69.9)		(69.9)	
Suit circuit assembly	49.0		49.0		49.0	
Cabin Recirculation Assy.	17.7		17.7		17.7	
CO_2 Sensor	3.2		3.2		3.2	
HEAT TRANSPORT SECTION	(38.9)		(148.9)		(115.9)	
Coolant Recirculation Assy.	7.0		7.0		7.0	
Controls - Primary Loop	26.4		26.4		26.4	
Controls - Redundant Loop	3.1		3.1		3.1	
Heat Exchangers (4)	2.4		2.4		2.4	
Radiator			95.0		62.0	
Condenser			15.0		15.0	
O_2 SUPPLY & Cn. PRESS. SECTION	(28.5)		(28.5)		(28.5)	
GOX Accumulator	18.0		18.0		18.0	
SOX Tank *						
WATER MANAGEMENT SECTION	(16.1)	(23.0)	(30.1)		(26.1)	
Water Tanks	10.0	23.0	24.4		20.0	
Controls	6.1		6.1		6.1	
PLUMBING - GAEC	(21.1)	(1.5)	(21.1)		(21.1)	
Atmosphere Revit. Section	.1		.1		.1	
Heat Transport Section	12.2	1.0	12.2		12.2	
O_2 Supply & Cbn. Press. Sect.	3.2		3.2		3.2	
Water Management Sect.	5.6	.5	5.6		5.6	

* Listed Under EPS

TABLE 9-12 ENVIRONMENTAL CONTROL SUBSYSTEM WEIGHTS (cont'd)*

ENVIRONMENTAL CONTROL SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
COLD PLATES **	(7.8)		(7.8)		(7.8)	
Cold Plates - Primary Loop	7.5		7.5		7.5	
Cold Plates - Redundant Loop	.3		.3		.3	
COOLANT	(34.5)		(34.5)		(34.5)	
Coolant-Primary Loop	31.2		31.2		31.2	
Coolant-Redundant Loop	3.3		3.3		3.3	
CONSUMABLES	(91.7)	(212.0)	(327.0)		(283.0)	
LiOH-ECS	14.4					
GOX	9.3		84.0		84.0	
SOX *						
Water ***	68.0	212.0	243.0		199.0	
STORAGE CONTAINER ASSEMBLY			(75.0)		(75.0)	
Container ****						
Heat Exchanger (2)			20		20	
Pumps & Motors			34		34	
Plumbing			5.0		5.0	
Controls			8.0		8.0	
Misc.			8.0		8.0	
Total ECS - Inert	(216.8)	(24.5)	(415.8)		378.8	
Total ECS-Expendables	(91.7)	(212.0)	(327.0)		(283.0)	

** Structural Cold Plates are included in Structures.

*** Includes Drinking Water

**** Assembly Utilizes GOX Accumulator

9.6.2 LEM Shelter

The LEM/S ECS must be capable of providing the same functions as the LEM ECS, i.e., atmosphere revitalization, oxygen supply and cabin pressurization control, water management and heat transport.

The atmosphere revitalization section hardware of the LEM ECS can be used for the LEM/S mission. However, an increased supply of expendable lithium hydroxide and activated charcoal must be included in the LEM/S. The usage rate and total weight of LiOH and activated charcoal are given in Table 9-13. Appendix A contains complete information on all ECS life support expendables.

The oxygen supply and cabin pressurization control section hardware used in the LEM, can be used in the LEM/S with the exception of the tankage. However, to minimize the LEM/S cg travel, the descent stage oxygen supply tank was relocated on the ascent stage. Here again, the LEM expendables were found to be inadequate for the LEM/S mission. The usage rates and total oxygen weight is given in Table 9-13.

A 2.5 ft^3 GOX accumulator is included in the LEM O_2 supply and cabin pressurization control section. The accumulator contains adequate O_2 for two cabin pressurizations. Considering the accumulator volume, the quantity of GOX, and the internal cabin pressure, the internal tank pressure is estimated to be approximately 620 psia. The GOX is supplied by the supercritical LOX storage tanks. The supercritical LOX tank pressure is approximately 800 psi. Since the LEM/S O_2 is stored subcritically, with a vent pressure of 100 psia, the existing GOX tank cannot be maintained at the required supply pressure without the addition of a pump.

A tank volume of approximately 16.5 ft^3 will be required for use with the LEM/S as a GOX accumulator containing sufficient O_2 for two cabin pressurizations. Due to space limitations a cylindrical tank with hemispherical end caps was used in lieu of a lighter spherical tank. The internal tank pressure is approximately 65 psia. The GOX accumulator is located in the aft equipment bay.

The LEM does not have an airlock, and incorporating an airlock in the LEM/S would require more than minimum modification to existing structure. An alternate method of conserving oxygen utilizes a storage container, intercoolers and a pumping system. The system is shown in Figure 9-13. Figure 9-14 indicates the weight saving to be realized by using the storage container as opposed to venting the cabin. This weight saving may be increased by using the GOX tank as the storage container.

TABLE 9-13

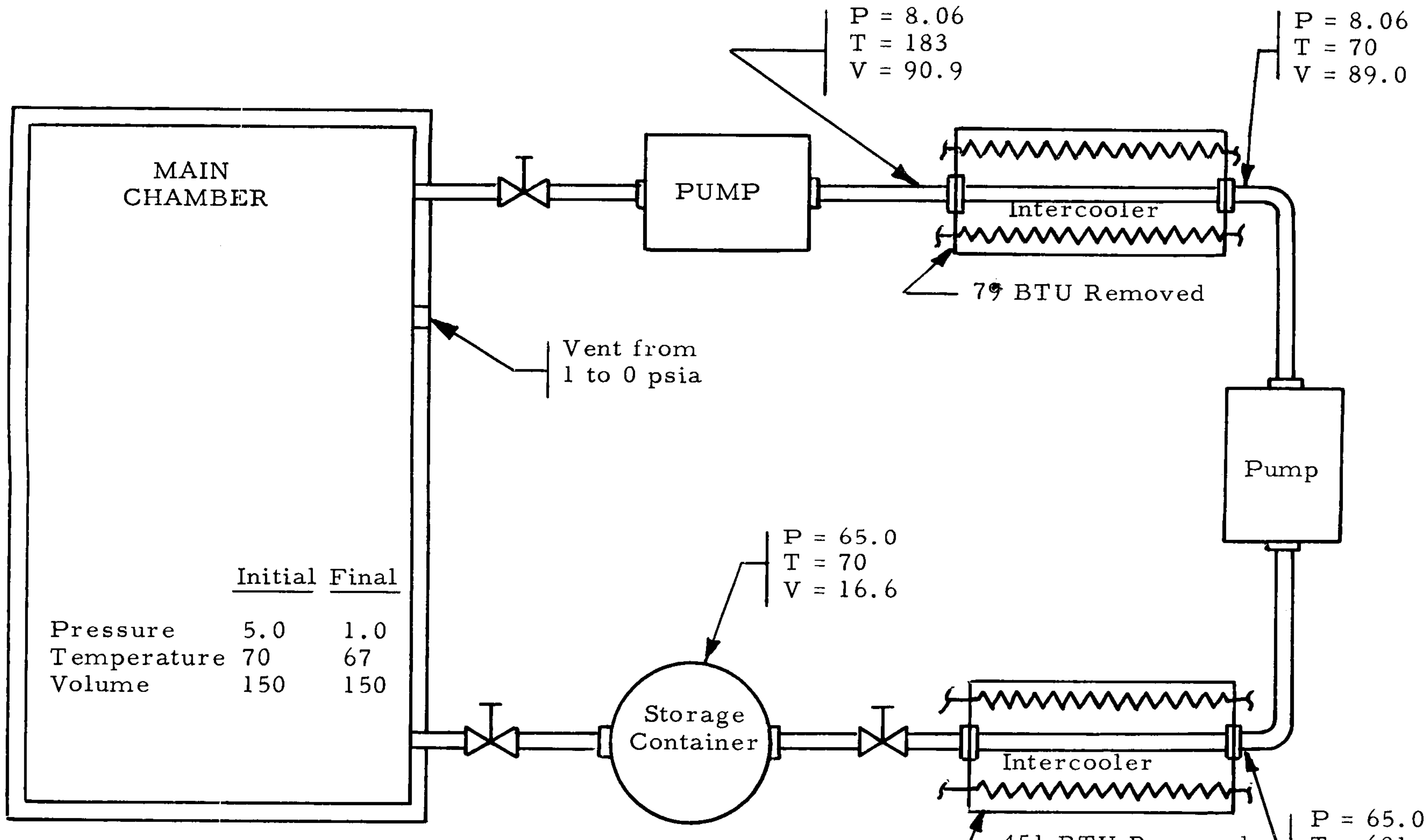
ECS EXPENDABLES FOR 2 MEN

EXPENDABLES	RATE lbs/Day	WT. 14 DAYS	50% CONT.	TOTAL WT.
Oxygen		(133)		(200)
Metabolic	4.52	63	32	95
Leakage	5.0	70	35	105
*LiOH & Charcoal	4.0	(56)	28	(84)
Water		(243)		(243)
Drinking & Hygiene	20.0	**	**	**
Cooling		243		

* The daily rate assumes one man to be using the PLSS LiOH and Charcoal for 8 hours per day.

** Drinking and hygiene water supplied by fuel cell.

BLANK PAGE 42



Notes:

1. Pressures shown are pounds per square inch absolute.
2. Temperatures shown are in degrees Fahrenheit.
3. Volumes shown are pounds per cubic foot.
4. The use of the second intercooler is based upon the ECS system requirements and the location of the storage container.

FIGURE 9-13 STORAGE CONTAINER SYSTEM SCHEMATIC

WEIGHT PENALTY-LEM CABIN
INGRESS-EGRESS

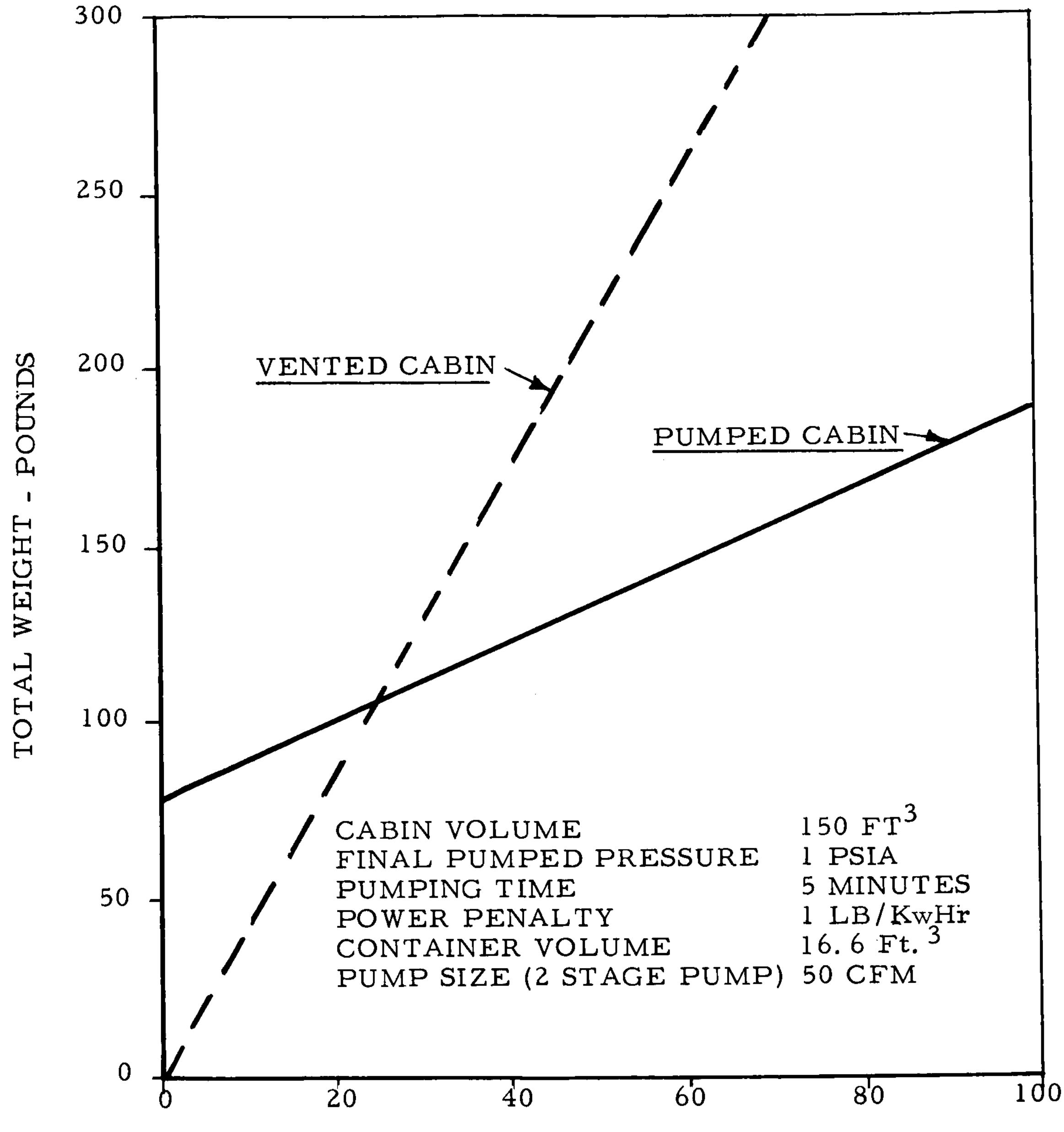


FIGURE 9-14
This Figure abstracted from Reference 12

Use of the GOX accumulator as a storage container would require that adequate O_2 for only one cabin refill be stored. After cabin pump down, the accumulator would contain O_2 for two cabin refills. Considering the weight saving, having an O_2 supply immediately available for only one cabin refill (instead of two) may be justified.

The water management section must provide water for the heat transport section and to meet the metabolic needs of the crew. In both instances the LEM water supply is insufficient for use in the LEM/S.

The LEM heat transport section dissipates heat by evaporation of water from the water management section. Heat dissipation by this method in the LEM/S would result in a severe weight penalty. This weight penalty can be shown as follows:

- From the LEM/S power profile (Figure 9-7) the continuous power of .95 kw required for operation of the ECS, communications, data handling, etc., was assumed to be the continuous heat load due to operation of LEM/S equipment. In addition a continuous metabolic heat load of .33 kw was assumed. The LEM/S heat load is;

  $$Q = .95 + .33 = 1.28 \text{ kw} = 4360 \text{ BTU/hr}$$

- For a 14 day (336 hr) mission the total heat load is;

  $$Q_T = 4360\ (336) = 1,464,900 \text{ BTU}$$

- The water required for cooling is;

  $$(WT_{H_2O}) = \frac{1,464,900 \text{ BTU}}{970 \text{ BTU/Lbs}} = 1510 \text{ lbs.}$$

- Considering the fuel cell water credit, and assuming drinking and hygienic water (except 70 lbs of urine) is reclaimed and 19.36 lbs of water lost from space suit per day; the water required from Earth launch is:

Item	Weight (Lbs)
Fuel Cell Water (466 kw-hrs)*	372
Urine & Feces Water	-79
PLSS	-271
Available for Cooling	22
Cooling Requirement	1510
Water Required from Launch	1488

*Based on 14 day active period power profile

- Without fuel cell water, the total water requirement is:

1488 + 372 = 1860 Pounds

This is obviously too high a weight penalty to pay to extend the existing LEM ECS system to satisfy the LEM/S mission with or without the fuel cell water credit.

An alternate heat transport section was developed which utilized a 95 ft^2 space radiator and 265 lbs. of water for supplemental cooling. The weight for this system is:

Item	Weight (Lbs)
Fuel Cell Water	372
Urine & Feces Water	- 79
PLSS (14 days)	-271
Supplemental Coolant	-265
Water Req'd from Launch	243
Radiator Wt + Condenser	110
Total	353

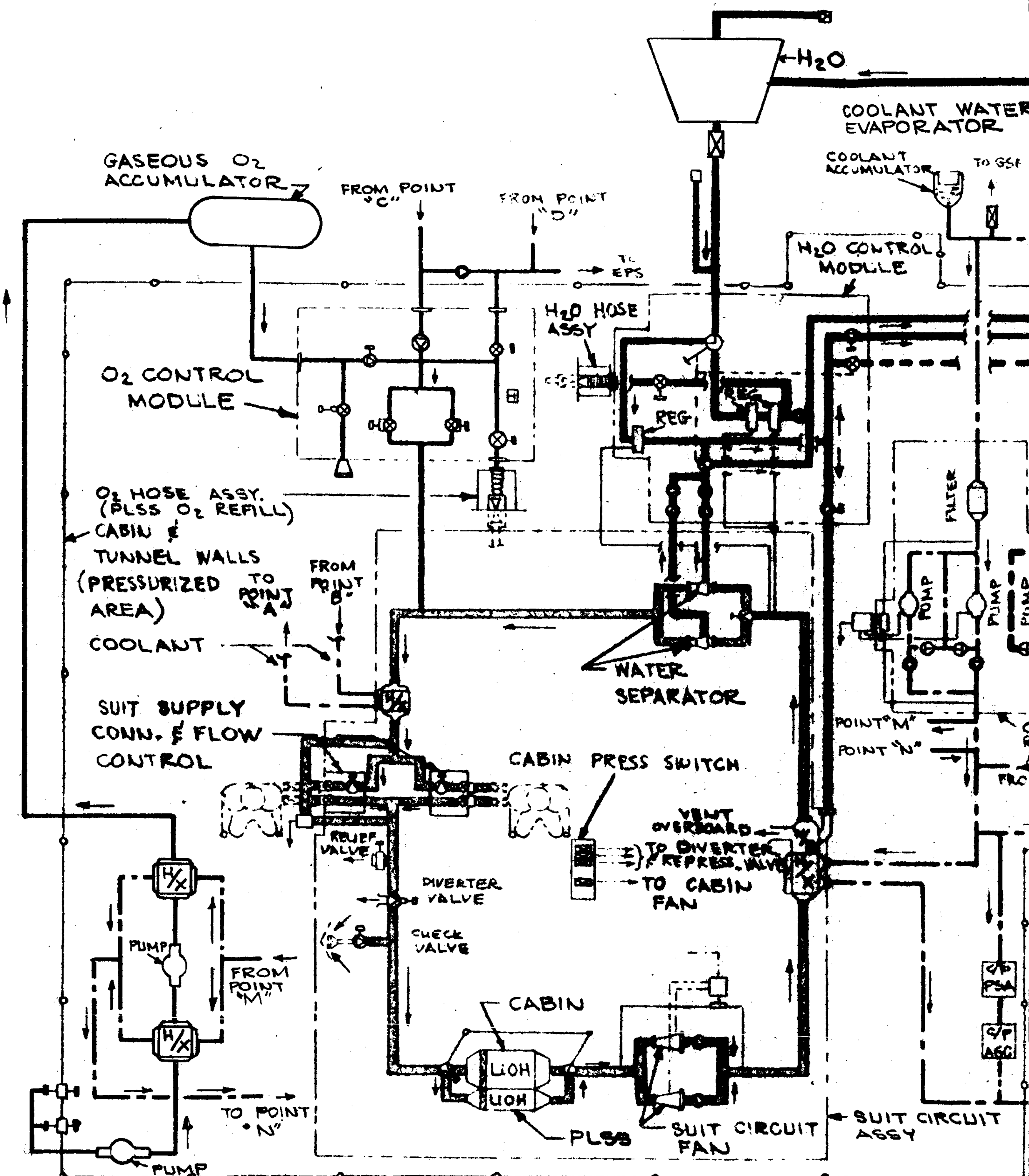
The preceding calculations indicate a weight saving of 1488-353 or 1135 pounds can be realized if the LEM/S ECS were to incorporate a radiator. The cooling water weight of 243 pounds required at Earth launch is also shown in Table 9-13.

The recommended LEM/S ECS schematic is shown in Figure 9-15. This differs from the LEM ECS schematic (Figure 9-12), in that a space radiator has been added to the primary and secondary coolant loops downstream from the cold plate section, a condenser has been added downstream from the primary and secondary coolant evaporators to cool the fuel cell water for storage, the LEM water storage tanks have been replaced by one larger tank with a water inlet from the fuel cells, and a cabin oxygen storage container assembly has been added. In addition, all ECS components have been relocated to the ascent stage.

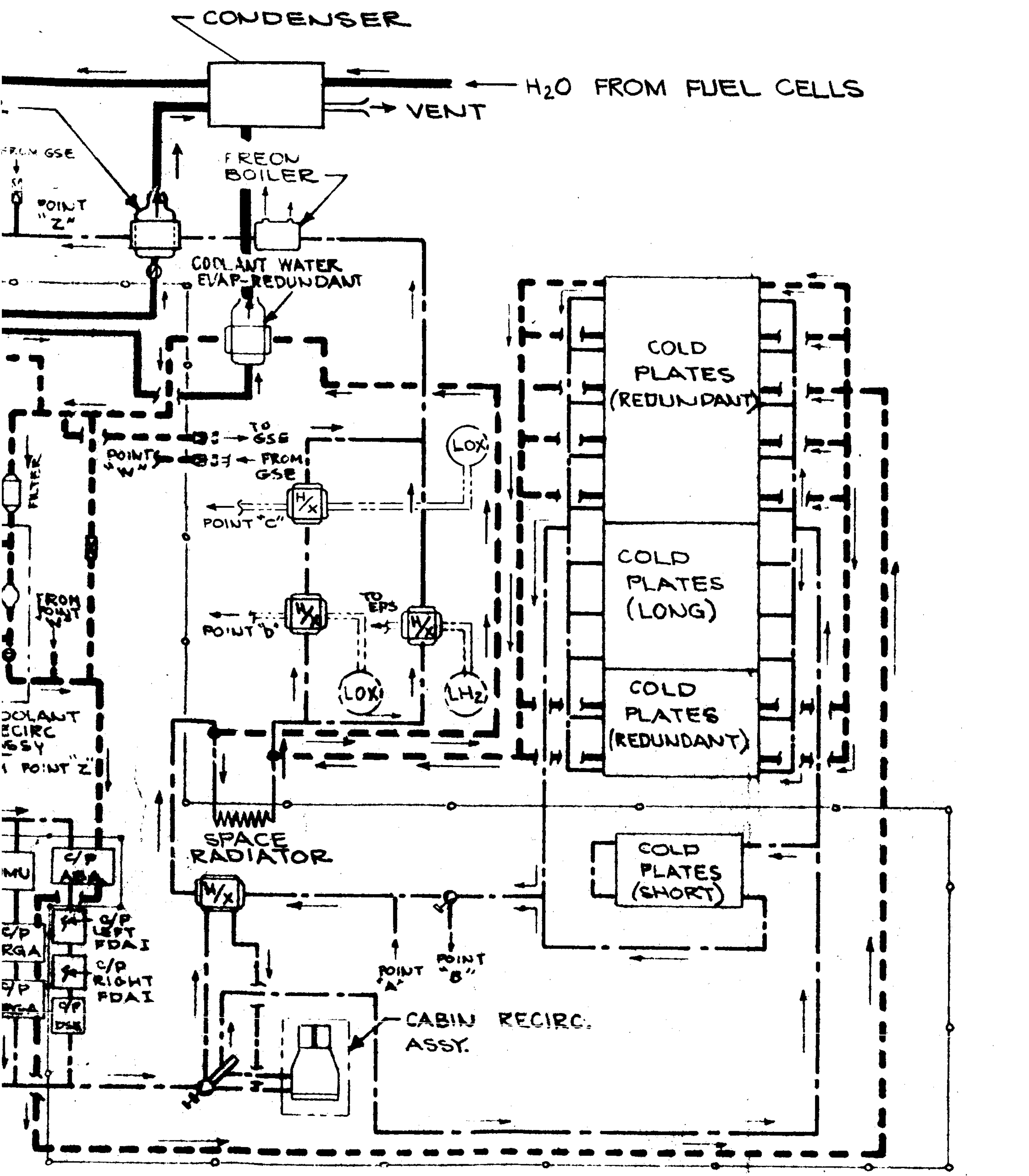
The LEM/S ECS weights are given in Table 9-12.

In addition to the cooling requirements already discussed, nonoperating equipment must be maintained within specific temperature limits. Figure 9-16 indicates the temperature profile for batteries and electronics packages during one lunar cycle. This curve assumes no internal heat generation, one inch of superinsulation and an α/ϵ ratio of 1.0. Additional information, including allowable package temperature limits, is shown in Table 9-14.

BLANK PAGE 98



LEM/S AND MOLEM ENVIRONMENTAL C
SCHEMATIC
ABSTRACTED FROM REF

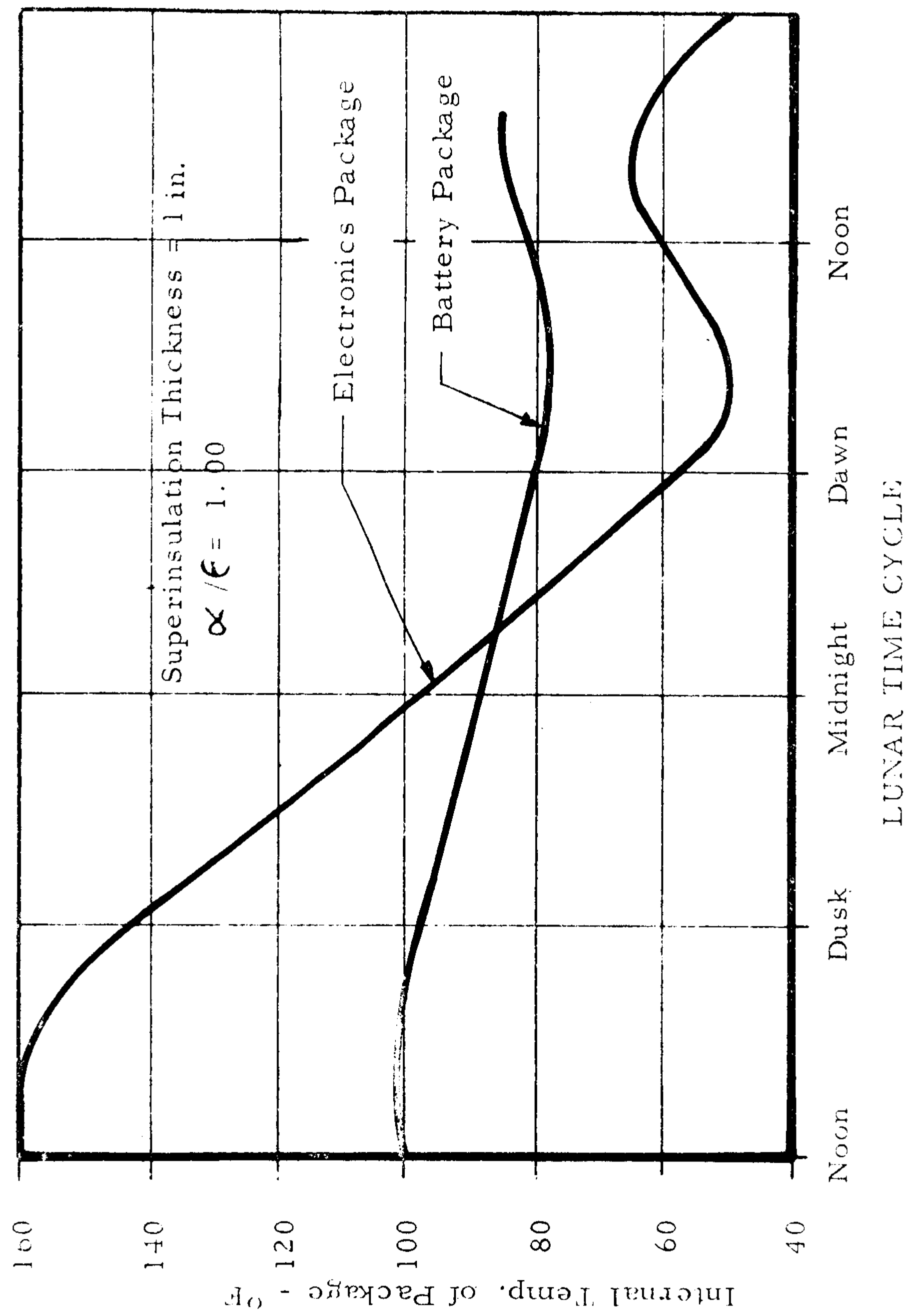


ONTROL SYSTEM

ERENCE 3

LEGEND:
PURE O_2
CONDITIONED O_2
PRIMARY COOLANT
SECONDARY COOLANT
WATER

FIGURE 9-15



TEMPERATURE PROFILE OF BATTERIES & ELECTRONICS PACKAGES
DURING
ONE LUNAR CYCLE
(Without Thermal Control)

FIGURE 9-16

TABLE 9-14

PACKAGE HEATING REQUIREMENTS

DURING DORMANCY PERIOD

THERMAL CONTROL DATA	ITEM OF EQUIPMENT	
	ELECTRONIC PACKAGES	BATTERY PACKAGES
Specific Heat, C_P (BTU/ lb -°F)	.126	.307
Package Temperature drop for each lunar cycle - °F	95	20
Thermal Control Heating (Watt-hr/lb)	3.5*	1.8*
Allowable Temperature Limits - °F	+160 to -40	+ 80 to + 40
WC_P/A (BTU/ft^2 - °F)	1* *	5 * *
W/A (lb/ft^2)	7.953 * *	16.278**

* This amount of electrical heat energy must be added (per lb. of package weight) at the end of each month of lunar storage (coincident with lunar noon) to return package to temperature at start of dormant period. Process repeated each month.

** Values furnished in Table for WC_P/A and W/A are based upon current acceptable design practices for electronics packages and batteries. The WC_P/A and W/A values established the C_P values also tabulated in Table.

By energizing electrical heaters, contained within the insulated packages, the internal package temperature can be maintained within the desired limits. If the heaters are energized at the end of one complete lunar cycle the heating energy required to return the packages to their initial temperature is noted in Table 9-14. The cycle then repeats itself each month. If no heat is added to the packages after the first lunar cycle the temperatures will continue on a downward trend.

9.6.3 MOLEM

The changes required for the basic LEM ECS hardware are minimal, are essentially the same as those required for the LEM/S, and are shown in Figure 9-15. Two water tanks are used for MOLEM to enable better cg control.

The ECS expendables required and their usage rates are the same as shown in Table 9-13 for the LEM/S excepting for cooling water. The MOLEM supplementary cooling water requirement with a 62 ft^2 ECS radiator is 199 pounds based upon following considerations:

ITEM	WEIGHT (LBS)
Fuel Cell Water (666 kw-hrs)	533
Crew water requirements (14 days)	-271
Sub total	262
Required for ECS Cooling	382
Excess Fuel Cell Water	-262
	120
Urine & Feces Water	+ 79
Water Required at Launch	199
Radiator Weight + Condenser Weight	77
Total	276

Nonoperating equipment temperature limits will be maintained as discussed in Section 9.6.2. The weights for the MOLEM ECS are given in Table 9-12.

9.7 REACTION CONTROL SUBSYSTEM

The Reaction Control Subsystem to be discussed in this section uses the same fuel and oxidizer used in the Propulsion Subsystems, i.e., 50-50 mixture of N_2H_4-UDMH fuel and N_2O_4 oxidizer. The oxidizer to fuel ratio is 2:1. This differs from the 1.6:1 ratio used in the Propulsion subsystems previously discussed. Helium is used as the system pressurant, and is stored at 3000 psi.

The thrust chambers are capable of developing 100 lbs of thrust in a pulsed mode, or steady state condition.

The RCS will be discussed with respect to the LEM, the LEM/S and MOLEM in this section.

9.7.1 LEM

The existing LEM RCS utilizes sixteen thrust chambers located on the ascent stage. The chambers are mounted in clusters of four, diametrically opposite and equally spaced about the LEM thrust line. The thrust chambers are supplied hypergolic propellant by two separate propellant feed and pressurization sections. The entire RCS is located within the ascent stage.

The RCS is used to stabilize the LEM vehicle during descent and ascent. The subsystem also provides control of the LEM vehicle attitude and translation about or along all axes during descent hover, rendezvous and docking.

The LEM RCS weight is given in Table 9-15.

9.7.2 LEM Shelter

Since the LEM/S will be landed on the lunar surface, attitude and translational control will be required. Therefore, an RCS is necessary. The existing LEM RCS can adequately meet the LEM/S requirements. However, a weight reduction can be realized by removing the RCS propellant associated with the ascent, rendezvous and docking phases of the mission.

The LEM/S RCS weight is given in Table 9-15.

TABLE 9-15 REACTION CONTROL SUBSYSTEM WEIGHTS*

REACTION CONTROL SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
REACTION CONTROL SUBSYSTEM	(855.1)		(487.7)		(487.7)	
PROPELLANT	(525.3)		(163.9)		(163.9)	
ΔV	340.8		28.4		28.4	
Attitude Control	93.8		67.5		67.5	
Parking Orbit Contingency	22.7					
Tank Failure Contingency	21.0		21.0		21.0	
Checkout	8.2		8.2		8.2	
Trapped	38.8		38.8		38.8	
PROPELLANT SYSTEM*	(151.5)		(145.1)		(145.1)	
Fuel Tanks	20.6		20.6		20.6	
Oxidizer Tanks	24.4		24.4		24.4	
Plumbing						
-Ascent Tie-In	6.0					
-Fuel & Oxidizer System **	64.9		64.9		64.9	
-Thruster Isolation Valves	35.2		35.2		35.2	
PRESSURIZATION SYSTEM	(57.2)		(57.2)		(57.2)	
Helium Tanks	21.0		21.0		21.0	
Helium Gas	2.1		2.1		2.1	
Plumbing	34.1		34.1		34.1	
* Capacity of usable propellant						
is 575.6#.						
** Includes Propellant Quantity						
Gaging (18.3#).						

TABLE 9-15 REACTION CONTROL SUBSYSTEM WEIGHTS (cont'd)*

REACTION CONTROL SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
Thruster Inst. Assy.	(121.5)		(121.5)		(121.5)	
Thrust Chamber Assy.	91.9		91.9		91.9	
Cluster Hardware	29.6		29.6		29.6	
TCA Failure Device *						
Total RCS - Inert	(368.6)		(362.6)		(362.6)	
Total RCS - Expendables	(486.5)		(125.1)		(125.1)	
-Att. Control Prop.	145.7		96.7		96.7	
ΔV Propellant	340.8		28.4		28.4	

[redacted]

* Included under Instrumentation sensors

9.7.3 MOLEM

The same changes are required for the MOLEM RCS as indicated for the LEM/S in Section 9.7.2. The required weights are also the same as shown in Table 9-15.

9.8 STABILIZATION AND CONTROL SUBSYSTEM

The Stabilization and Control subsystem being considered for use in the LEM, LEM/S and the MOLEM, interfaces with the N&GS and the RCS. The LEM SCS and its compatibility with the other two payload configurations mentioned above will be discussed in this section.

9.8.1 LEM

The SCS consists of two main groups, i.e., the Control Electronics Section (CES) and the Abort Guidance Section (AGS).

The CES consists of an Attitude Translation Control Assembly (ATCA), two (2) Rate Gyro Assemblies (RGA), Descent Engine Control Assembly (DECA), two (2) Gimbal Drive Actuators (GDA), two (2) Attitude Controller Assemblies (ACA) and two (2) Translation Controller Assemblies (TCA).

The AGS consists of a Control and Inflight Monitor Assembly (IFMA), an Attitude Reference Assembly (ARA), and an Abort Programmer Assembly (APA).

The CES converts attitude errors, rate, or translation commands from the N&GS, the AGS, or manually operated cockpit controls to pulsed signals for firing the RCS. The CES provides capability for fully automatic control or for manual control of the SCS.

The AGS provides abort capability from any point during the powered descent, or ascent, attitude reference for vehicle stabilization, and ascent capabilities from the lunar surface. LEM attitude error signals are generated by the AGS to actuate the appropriate RCS thrusters.

The LEM SCS weights are given in Table 9-16.

9.8.2 LEM Shelter

All functions required to land the unmanned LEM/S on the lunar surface can be satisfied by the existing LEM SCS.

The LEM/S will require no abort capability, due to the unmanned mode of operation during descent. Some constituents of the AGS may therefore, be omitted from the LEM/S SCS. However, since it was not known to what extent the items of equipment within the AGS interface with other subsystems, the LEM SCS was used intact. The weight of the LEM/S SCS components is given in Table 9-16.

TABLE 9-16 STABILIZATION AND CONTROL SUBSYSTEM WEIGHTS*

STABILIZATION & CONTROL SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
STABILIZATION AND CONTROL	(70.6)	(13.7)	(70.6)	(13.7)	(70.6)	(13.7)
ATT. TRANSLATION CONTROL	27.0		27.0		27.0	
ASSY.	3.6		3.6		3.6	
RATE GYRO ASSEMBLY (2)	4.0		4.0		4.0	
DESCENT ENGINE CONTROL SYST.		(13.7)		(13.7)		(13.7)
Descent Engine Control Assy.		6.8		6.8		6.8
Gimbal Drive Actuators (2)		6.9		6.9		6.9
ABORT GUIDANCE SYSTEM	(36.0)		(36.0)		(36.0)	
Abort Sensor Assembly *	15.0		15.0		15.0	
Abort Electronic Assembly **	21.0		21.0		21.0	
INFLIGHT MONITOR FUNCTIONS	(4.0)		(4.0)		(4.0)	

[redacted]

* Includes sensor package and power supply.

** Includes electronics and programmer.

9.8.3 MOLEM

No changes will be made for the MOLEM SCS for the same reasons given in Section 9.8.2 for the LEM/S. The weight of the SCS is shown in Table 9-16.

9.9 COMMUNICATIONS SUBSYSTEM

The communications subsystem to be discussed in this section provides the necessary link between the landed payload, the crewman outside the vehicle, Earth and the CM/SM.

9.9.1 LEM

The LEM Communications subsystem provides the necessary communications links by utilizing two radio frequency sections (VHF and UHF), a television section and a signal processing section. Figure 9-17 shows a simplified block diagram of the LEM subsystem.

The VHF section is used to transmit voice (two-way) and biomedical information between the crewman on the lunar surface and the LEM, and for two-way voice communications between LEM and the CM/SM. VHF communications with the extravehicular astronaut are maintained for transmission of voice and biomedical information to the LEM. This information is monitored by the onboard crewman and relayed to Earth via the UHF, or S-Band, section. The LEM communication links are shown in Figure 9-18.

Voice communications from the CM/SM and Earth are received by the LEM. This communication is transmitted to the LEM crewman's headset, or is rerouted through the audio centers for transmission to the extravehicular crewman. All VHF communications links are line-of-sight.

The S-Band communications link is capable of receiving and transmitting signals simultaneously. The S-Band section is used to transmit voice, T. V. and coded signals, indicating the status of the extravehicular astronaut and LEM subsystems, to Earth. Two S-Band inflight antennas are used as backup voice communication between the LEM and the CM/SM.

The television section includes a portable T. V. camera to be used by the crewman on the lunar surface within 80 feet of the LEM via "hardline".

The LEM communications subsystem weight is given in Table 9-17.

9.9.2 LEM/S

The LEM/S communications subsystem will be required to furnish all of the communications links available in the LEM, plus two

LEM COMMUNICATIONS BLOCK DIAGRAM

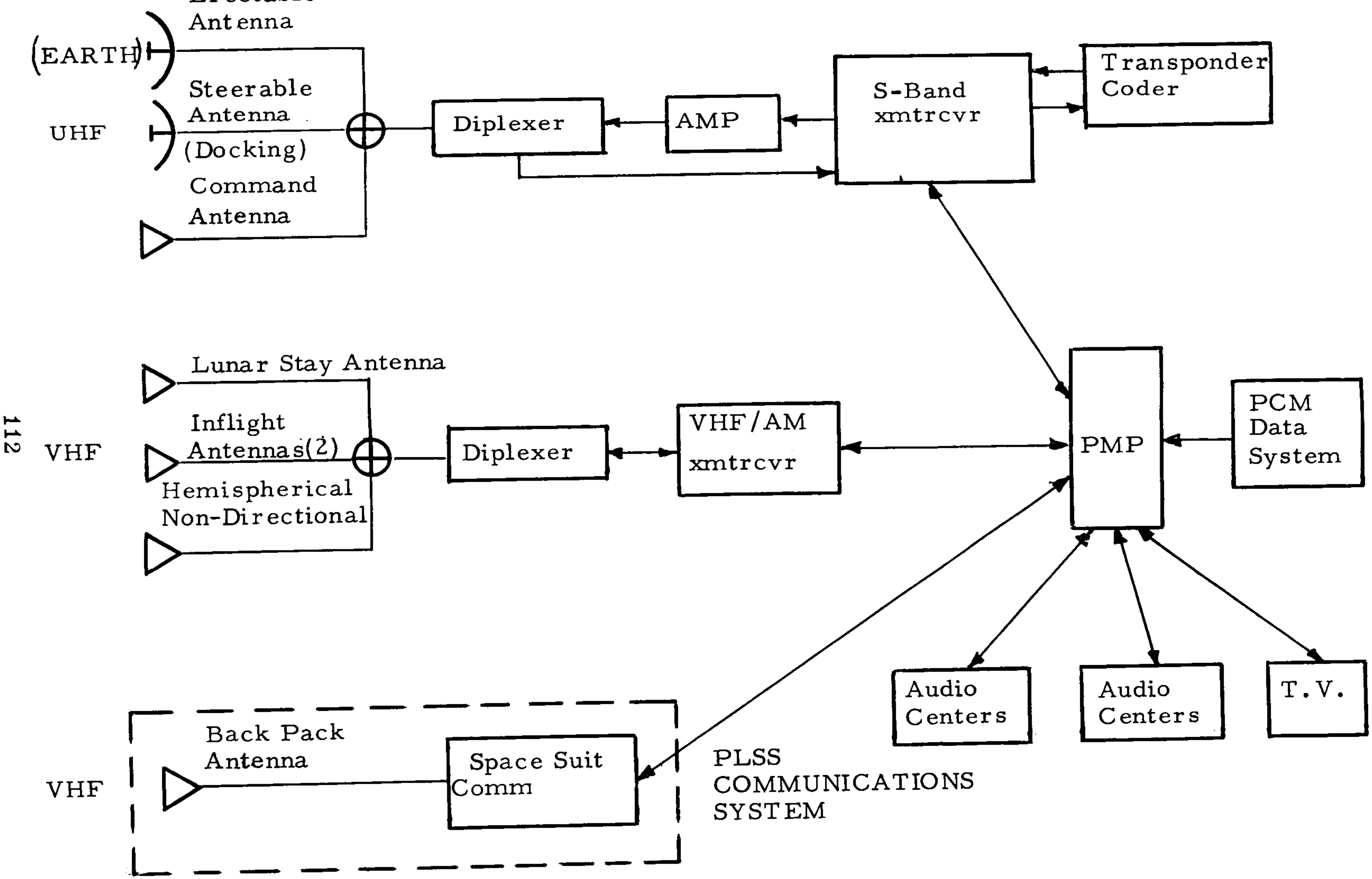


FIGURE 9-17

LEM COMMUNICATIONS
LINKS

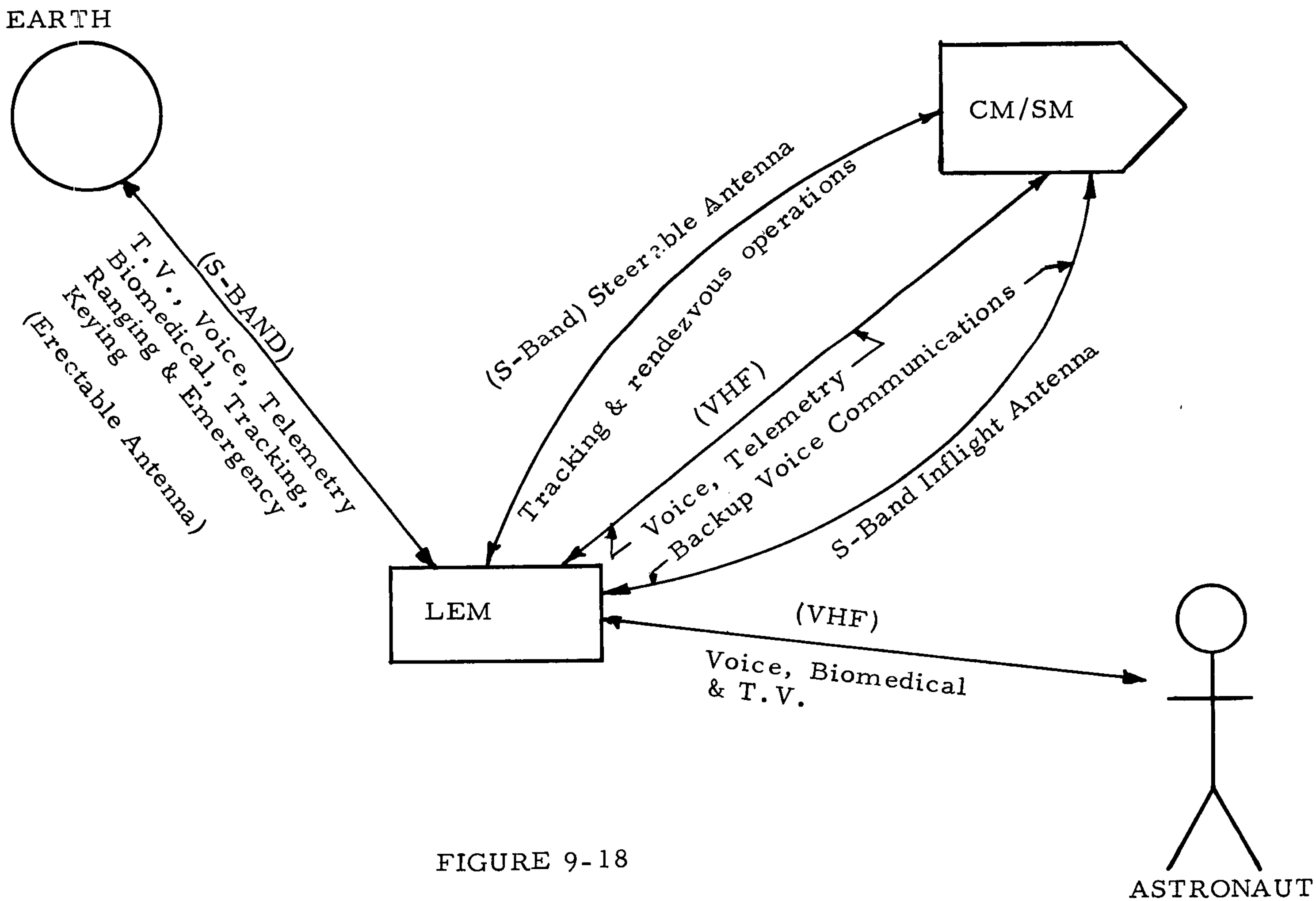


FIGURE 9-18

other links. The two other links required, as shown in Figure 9-19, are between the LEM/S and LEM, and the LEM/S and LSSM. An additional requirement exists for incorporating remote control capability for operation of the LSSM and subsystems checkout during the dormant period.

To extend the LEM subsystem capability two command units are required (one in the UHF section and one in the VHF section). Each unit consists of a command decoder and a command detector.

The UHF command decoder receives signals from earth to initiate remote systems checkout, or control of the LSSM. The command decoder output is fed directly into the Telecommunications Data Programmer.

The VHF command decoder performs the same function as the UHF command decoder. The command signals however, originate in the LEM, or the CM/SM.

To accomplish unloading of the LSSM a requirement exists for an additional T.V. camera and a command umbilical from the LEM/S to the LSSM. After unloading, this camera can be used in conjunction with the scientific instrumentation previously discussed in Section 9.5.2. The command umbilical will be used for LSSM subsystems checkout after unloading.

The existing LEM-S Band Steerable Antenna is a medium gain antenna used for communication between the LEM and CM/SM during the LEM orbit, descent, ascent, rendezvous and docking phases of the mission. The antenna is mounted on a double gimbal that is servo controlled. This antenna will not be required on the LEM/S and has been removed.

The S-Band erectable antenna which utilizes an aiming telescope will be used for communication between the LEM/S and earth.

The LEM/S communications subsystem is shown in the simplified block diagram in Figure 9-20.

The subsystem weights are given in Table 9-17.

LEM/S COMMUNICATION LINKS

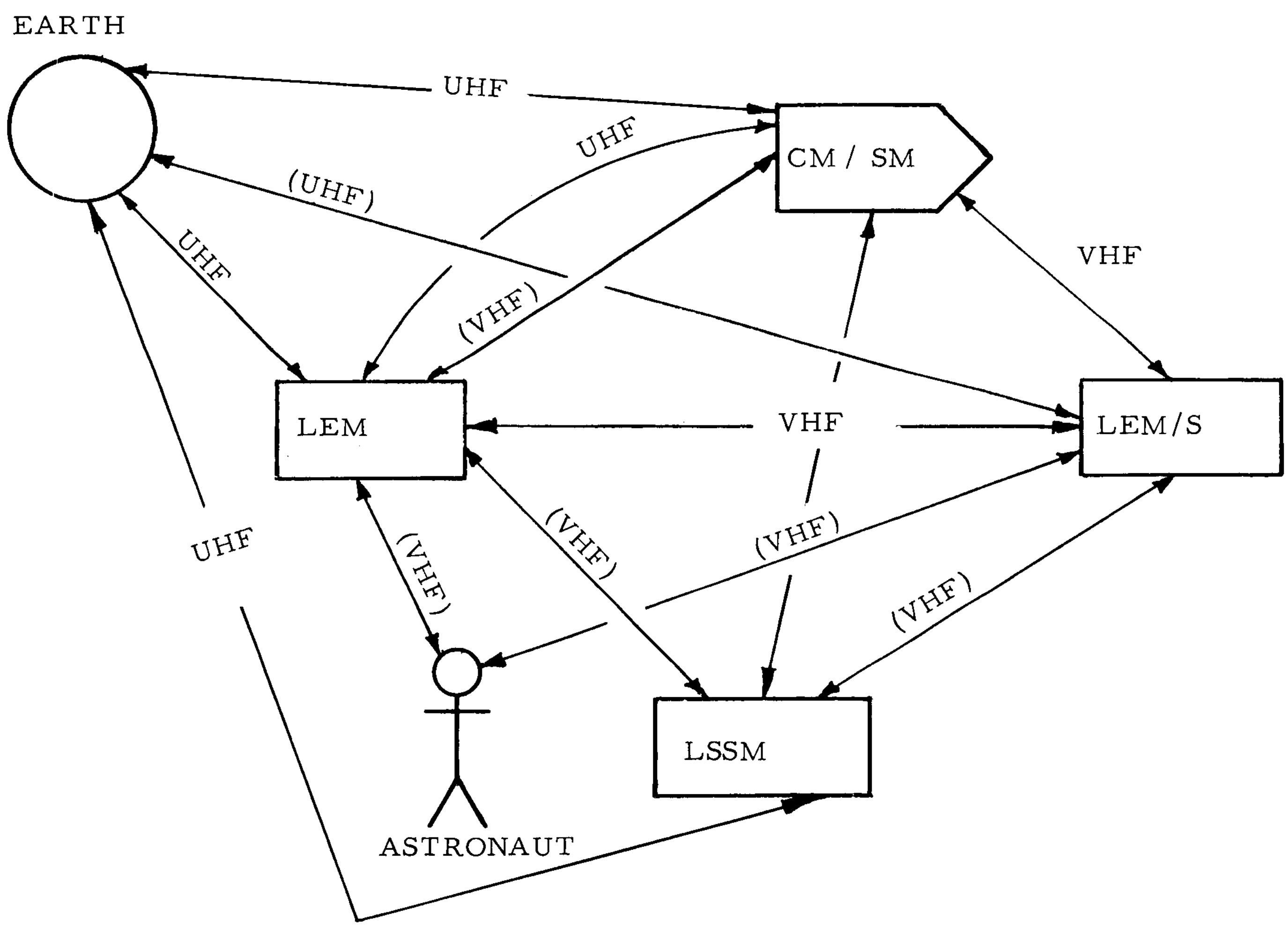


FIGURE 9-19

LEM/S COMMUNICATIONS BLOCK DIAGRAM

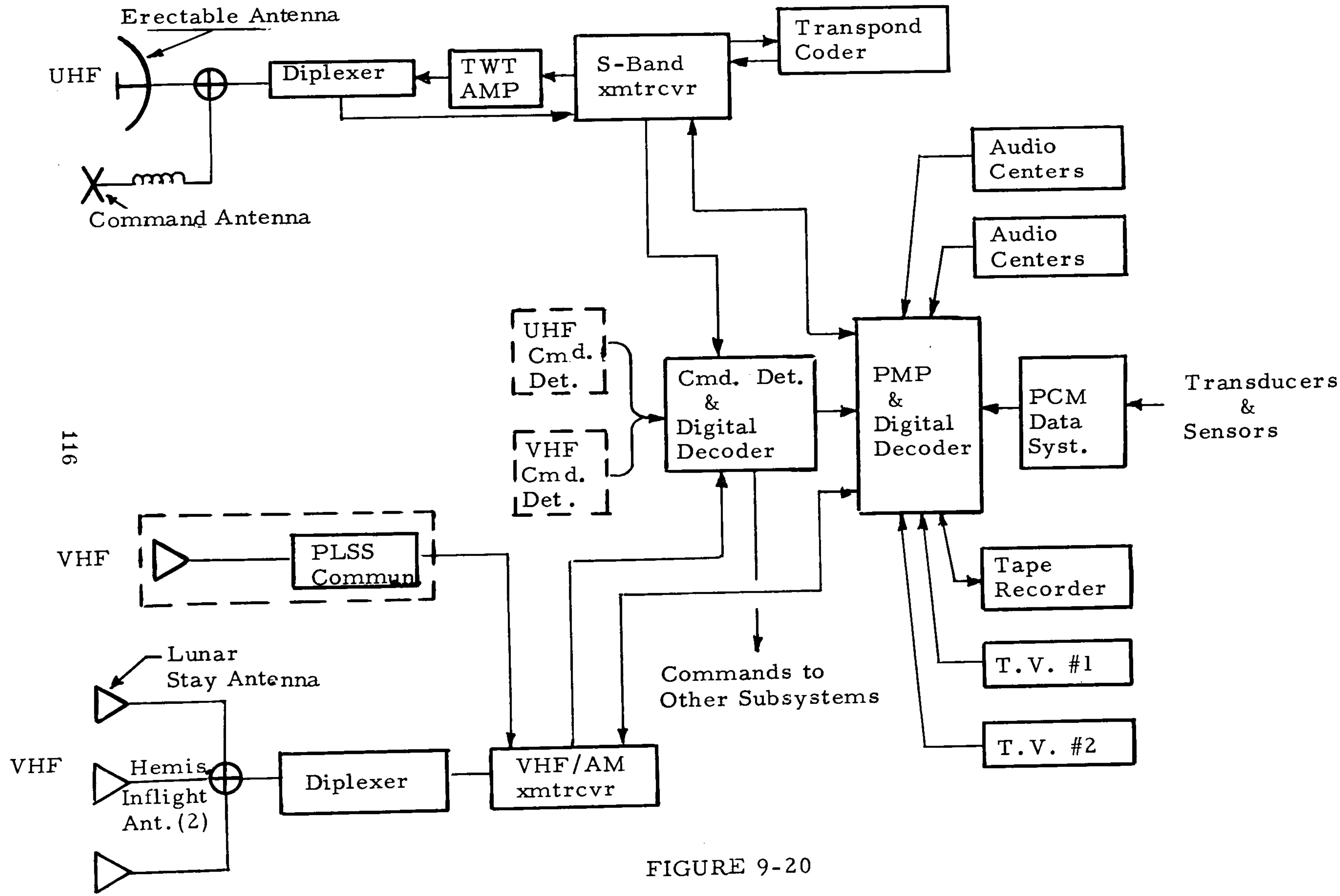


FIGURE 9-20

TABLE 9-17 COMMUNICATIONS SUBSYSTEM WEIGHTS*

COMMUNICATIONS SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
COMMUNICATIONS	(117.7)	(27.3)	(110.2)	(38.8)	(151.9)	(1.5)
VHF LEM/CM	(42.7)	(13.2)	(42.7)	(13.2)	(53.3)	
VHF-Signal Processing ERA*	27.5		27.5		27.5	
Inflight Antenna (2)	3.3		3.3		3.3	
Lunar Stay Antenna (1)		10.6		10.6	13.2	
R. F. Switch	1.1		1.1		1.1	
B. H. Flanges (3)	.4		.4		.4	
R. F. Cables	7.8	2.6	7.8	2.6	7.8	
EVA Antenna	2.6		2.6		2.6	
S-BAND LEM/EARTH	(65.0)	(12.6)	(48.0)	(12.6)	(67.6)	
S-Band ERA **	37.5		37.5		37.5	
Inflight Antenna (2)	2.3		2.3		2.3	
Erectable Antenna		10.0		10.0	17.0	
Steerable Antenna ***	17.0					
R. F. Switch	1.0		1.0		1.0	
B. H. Flanges (4)	.5		.5		.5	
R. F. Cables	6.7	2.6	6.7	2.6	9.3	
TELEVISION		(1.5)	(11.5)	(11.5)	(23.0)	
Camera, Portable - GFE			11.5	11.5	23.0	
Lens - GFE	10.0					
Camera Thermal Equip-GFE						
Cable		1.5		1.5		1.5

* Includes Premodulation Processor and Audio Center 8.3#, Triplexer 3.5#, Transceivers (2) 9.5#, Case and Connectors 5.2#, and Lunar Stay Antenna Switch 1.0#.

[redacted]

TABLE 9-17 COMMUNICATIONS SUBSYSTEM WEIGHTS (cont'd)*

COMMUNICATIONS SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
COMMUNICATIONS (continued)						
Command Detector & Decoder			(8.0)		(8.0)	

** Includes Transceiver 17.9#, Power Amplifier (including notch filter) 12.2#, Diplexer 1.0#, Antenna Electronics 1.5#, and Case and Connectors 4.9#.

*** Includes Earth Sensor and Drive.

9.9.3 MOLEM

The LEM communications equipment is adequate for MOLEM with the exception of the remote control requirement of the vehicle. The remote control equipment is required for both directing the unloading operation and for driving of the vehicle.

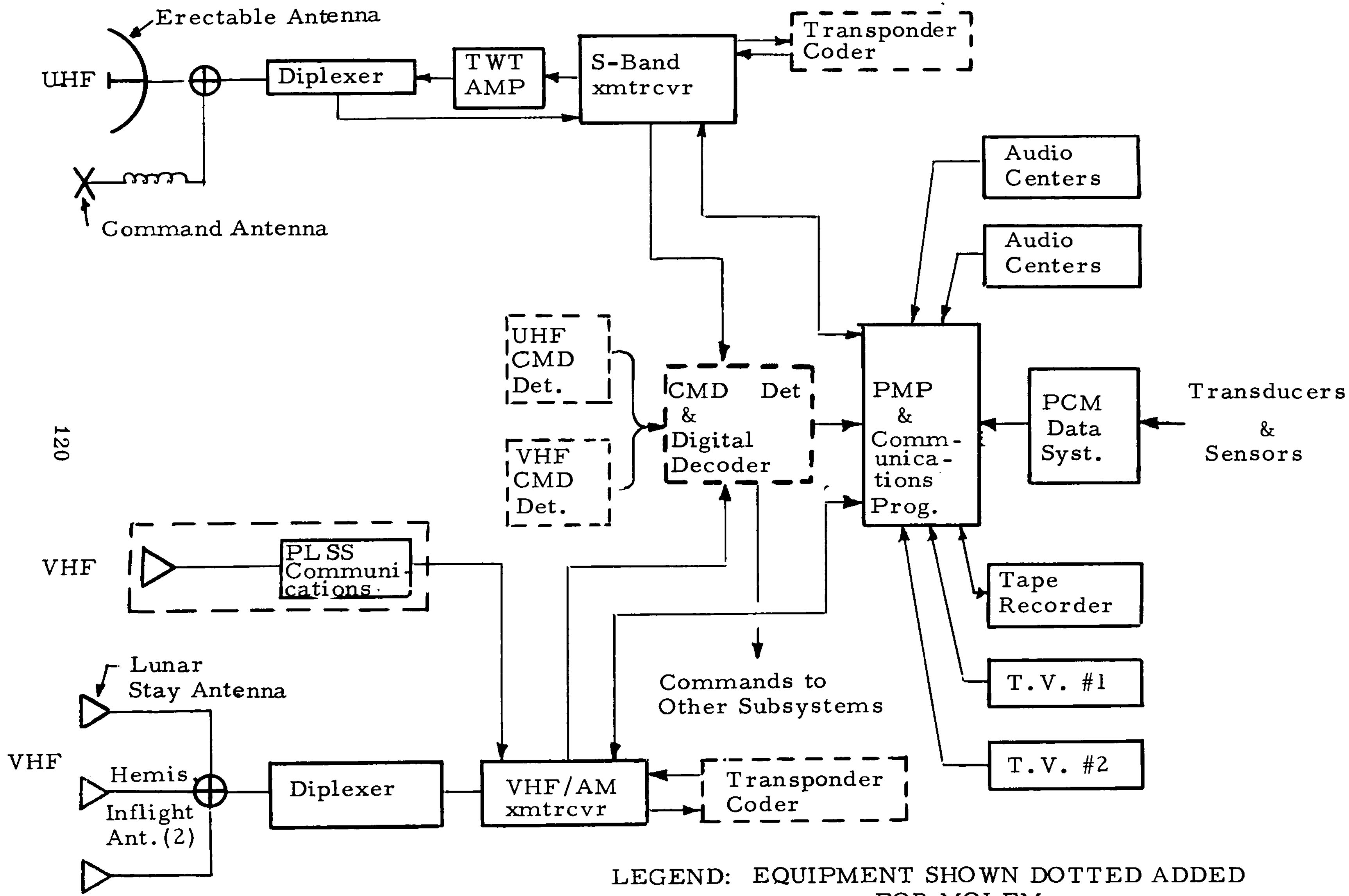
Earth control is necessary to effectively accomplish the remote control operations. Also, backup control from the Apollo C/M is required and remote control is additionally desired from LEM to command drive MOLEM when necessary. Two command decoders are therefore required, one UHF for Earth station control and one VHF for Apollo C/M and LEM control as shown in Figure 9-21. Each decoder consists of two separate functional sections, a Command Code Detector and a Command Decoder. The output from the Command Decoder is fed directly to the Telecommunications Data Programmer. A stereo TV camera system will also be required to remotely unload MOLEM.

The steerable S-Band antenna, now on LEM, will be removed for the MOLEM application. This antenna is useful only in the manned mode of the LEM orbit, descent, ascent, rendezvous and docking with the Apollo C/M.

The VHF lunar stay antenna and the S-Band erectable antenna were removed from the descent stage and added to the MOLEM, or upper stage. A servo-controlled gimbal mount will be required for the erectable antenna and may be obtained by modifying the steerable S-band antenna mount. The gimbal mount is required to allow the erectable antenna to "lock-in" on Earth while MOLEM is traversing the lunar surface. Should the existing erectable antenna be structurally inadequate for the shock loads resulting from the lunar traverse, a new or modified antenna will be required. Sufficient information was not available to determine the structural integrity of the LEM erectable antenna.

The weights for the required MOLEM Communications equipment are tabulated in Table 9-17.

MOLEM COMMUNICATIONS BLOCK DIAGRAM



LEGEND: EQUIPMENT SHOWN DOTTED ADDED FOR MOLEM

FIGURE 9-21

9.10 LANDING SUBSYSTEM

The landing system to be discussed in this section was designed to soft land a payload on the lunar surface.

The landing system design assumed the lunar surface bearing strength to be sufficient to support the landed payload. Some apparently contradictory evidence has been recently obtained through the Ranger program which indicates the lunar surface bearing strength may not adequately support payloads in the weight category being considered in this report.

For the purpose of this report however, the previously assumed design data will be considered valid.

9.10.1 LEM

The LEM landing gear consists of four telescoping primary struts, eight secondary struts, four landing pads and eight deployment and downlock mechanisms. The LEM landing gear configuration can be seen in Figure 3-1 and Figure 3-3.

Honeycomb energy absorption devices have been included in the primary struts to minimize the impact loads encountered at lunar touchdown.

The LEM landing gear weight is given in Table 9-18.

9.10.2 LEM Shelter

The LEM/S total weight has not changed sufficiently from the LEM total weight nor has the overall cg shifted significantly. Therefore, the existing LEM landing gear appears to be adequate for the LEM/S mission. The landing gear subsystem weights are given in Table 9-18 for the LEM/S.

9.10.3 MOLEM

The MOLEM overall weight is less than the weight of the existing LEM and the MOLEM cg has not shifted significantly from the LEM cg.

The existing LEM landing gear is therefore adequate for use in the MOLEM mission. The MOLEM landing gear subsystem weights are shown in Table 9-18.

TABLE 9-18 LANDING GEAR SUBSYSTEM WEIGHTS*

LANDING GEAR SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
LANDING GEAR - (4 GEAR)		(410)		(410)		(410.0)
PRIMARY STRUTS		(160.8)		(160.8)		(160.8)
Tubes		122.8		122.8		122.8
Fittings		24.0		24.0		24.0
Shocks		14.0		14.0		14.0
SECONDARY STRUTS		(48.4)		(48.4)		(48.4)
Tubes		12.8		12.8		12.8
Fittings		11.6		11.6		11.6
Shocks		24.0		24.0		24.0
EXTENSION MECHANISM		(74.9)		(74.9)		(74.9)
Downlock		36.8		36.8		36.8
Uplock		10.0		10.0		10.0
Deployment *		10.0		10.0		10.0
Misc. Locking		18.0		18.0		18.0
PADS AND FITTINGS		(46.0)		(46.0)		(46.0)
Pads		36.0		36.0		36.0
Fittings		10.0		10.0		10.0
LANDING GEAR/STRUCTURE TRUSS		(72.0)		(72.0)		(72.0)
Truss Tubes		48.0		48.0		48.0
Fittings		24.0		24.0		24.0
THERMAL PAINT		(8.0)		(8.0)		(8.0)

* Includes Instrumentation and deployment sensors.

9.11 CONTROLS AND DISPLAYS SUBSYSTEM

Controls, in general, consist of manually operated switches, dials, levers, etc., used to change the status of subsystems. Displays consist of two main types; visual and auditory. Displays are used to indicate the status of subsystems under normal and/or emergency conditions.

The controls and displays used in the LEM and their applicability to the LEM/S and MOLEM will be discussed in this section.

9.11.1 LEM

The controls and displays provided in the LEM for the purpose of changing and monitoring the vehicle's status have been located primarily in the forward portion of the crew compartment. Two main consoles are located on either side of the crew compartment at the Commander's station and at the System Engineer's station. In addition, controls and displays have been located in the upper, center portion of the forward bulkhead. which consist mainly of flight controls.

Placement of the controls and displays in the existing LEM was based on visibility, frequency of operation, accessibility, etc. Controls and displays considered critical, from the standpoint of vehicl- and crew safety, have been centrally located and in some instances duplicated on the Commander's and System Engineer's control console.

The weight charged to controls and displays is listed in Table 9-19.

9.11.2 LEM Shelter

All flight controls and displays for the unmanned LEM/S during the flight phase of its mission may be eliminated. The LEM crew stations have been significantly modified for use in the LEM/S, therefore, duplication of controls and displays is not considered necessary.

By eliminating duplication and all controls and displays associated with the flight phase of the LEM mission, the controls and displays for the LEM/S can be combined into one console. The elimination of the Flight Engineer's console is required in order to store the additional expendables needed for the longer duration LEM/S mission.

TABLE 9-19 CONTROLS AND DISPLAYS SUBSYSTEM WEIGHTS*

CONTROLS & DISPLAYS SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
CONTROLS AND DISPLAYS	(236.3)		(88.2)		(118.2)	
STRUCTURE						
STABILIZATION AND CONTROLS	(70.3)					
Flight Controls	54.7					
Back-Up Guidance	7.8					
ΔV Panel	7.8					
NAVIGATION AND GUIDANCE	(43.8)					
GFE	41.5					
Rendezvous & Landing Radar	2.3					
CREW PROVISIONS	(3.3)		(3.3)		(3.3)	
ENVIRONMENTAL CONTROL	(13.1)		(13.1)		(13.1)	
LUNAR LANDING SYSTEM						
INSTRUMENTATION	(9.1)		(9.1)		(9.1)	
ELECTRICAL POWER	(23.3)		(23.3)		(23.3)	
Cryogenic Storage	12.9		12.9		12.9	
D. C. Power Distribution	4.0		4.0		4.0	
A. C. Power Distribution	1.2		1.2		1.2	
Pyrotechnic Subsystem	5.2		5.2		5.2	
PROPULSION	(10.0)					
REACTION CONTROL	(16.0)					
COMMUNICATIONS	(14.4)		(14.4)		(14.4)	
INSTRUMENT PANEL AND SIDE CONSOLES	(33.0)		(25.0)		(25.0)	
NAVIGATION & GUIDANCE					(15.0)	
LOCOMOTION					(15.0)	

The work required for rewiring has been minimized by incorporating all controls and displays into the Systems Engineer's console and into a small panel on the forward bulkhead.

The C&DS has been discussed in Section 9.3.2 and is shown in Figure 9-3 which is repeated for convenience. The LEM/S controls and displays weight is shown in Table 9-19.

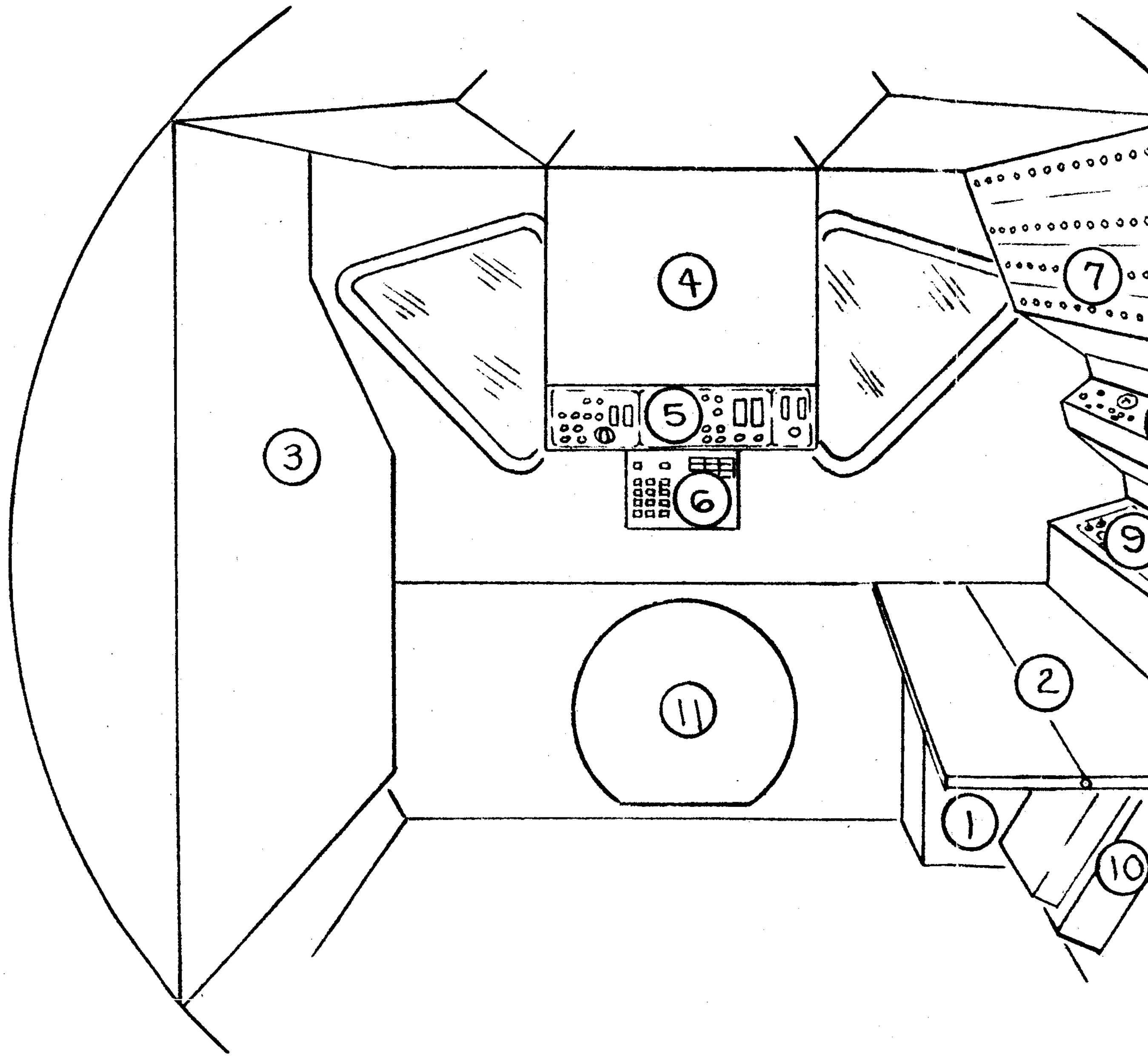
9.11.3 MOLEM

All flight Controls and Displays used on LEM have been eliminated for the MOLEM mission. The flight controls and displays are no longer required due to unmanned descent mode to the lunar surface.

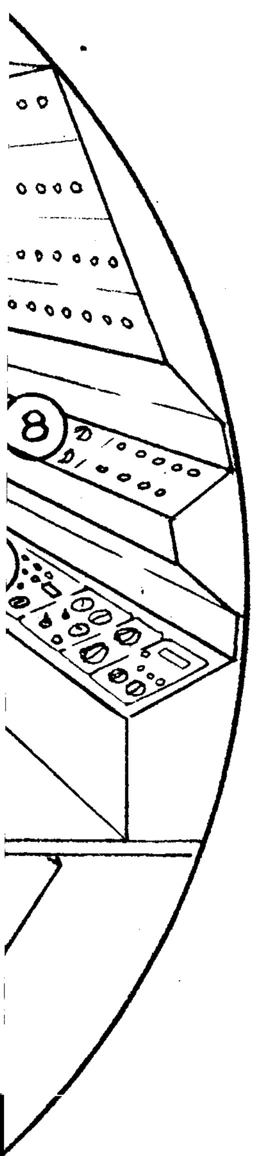
The C&DS for the MOLEM is shown in Figure 9-6 which is repeated for convenience. The majority of the controls and displays are located on the right hand side of the vehicle, the station occupied by the System Engineer on the LEM, as shown in Figure 9-6 and discussed in Section 9.3.3. The items added for the N&GS include 8 pounds for the position plotter, 2 pounds for the odometer and 5 pounds for required modifications to the control panel. The items added for the locomotion system include 5 pounds for the locomotion control lever and 10 pounds for the locomotion control panel.

The weights for the C&DS are shown in Table 9-19.

BLANK PAGE 126



CREW STATIONS — CONTROLS & DISPLAYS
LEM/S CONCEPT



1. STORAGE FOR SCIENTIFIC EQUIPMENT

2. WORK TABLE

3. STORAGE FOR LiOH (ECS) AND MISCELLANEOUS EQUIP.

4. STORAGE FOR LiOH (PLSS) AND FIRST AID

5. CONTROL AND DISPLAY PANEL FOR LIGHTING, POWER GENERATOR AND CRYOGENIC STORAGE

6. CONTROL AND DISPLAY PANEL FOR ACTIVITY PROGRAMMER AND TELESCOPE

7. CONTROL AND DISPLAY PANEL FOR ENVIRONMENTAL CONTROL, COMMUNICATIONS, ELECTRIC POWER SYSTEM, INSTRUM., T. V., AND CRYOGENIC STORAGE

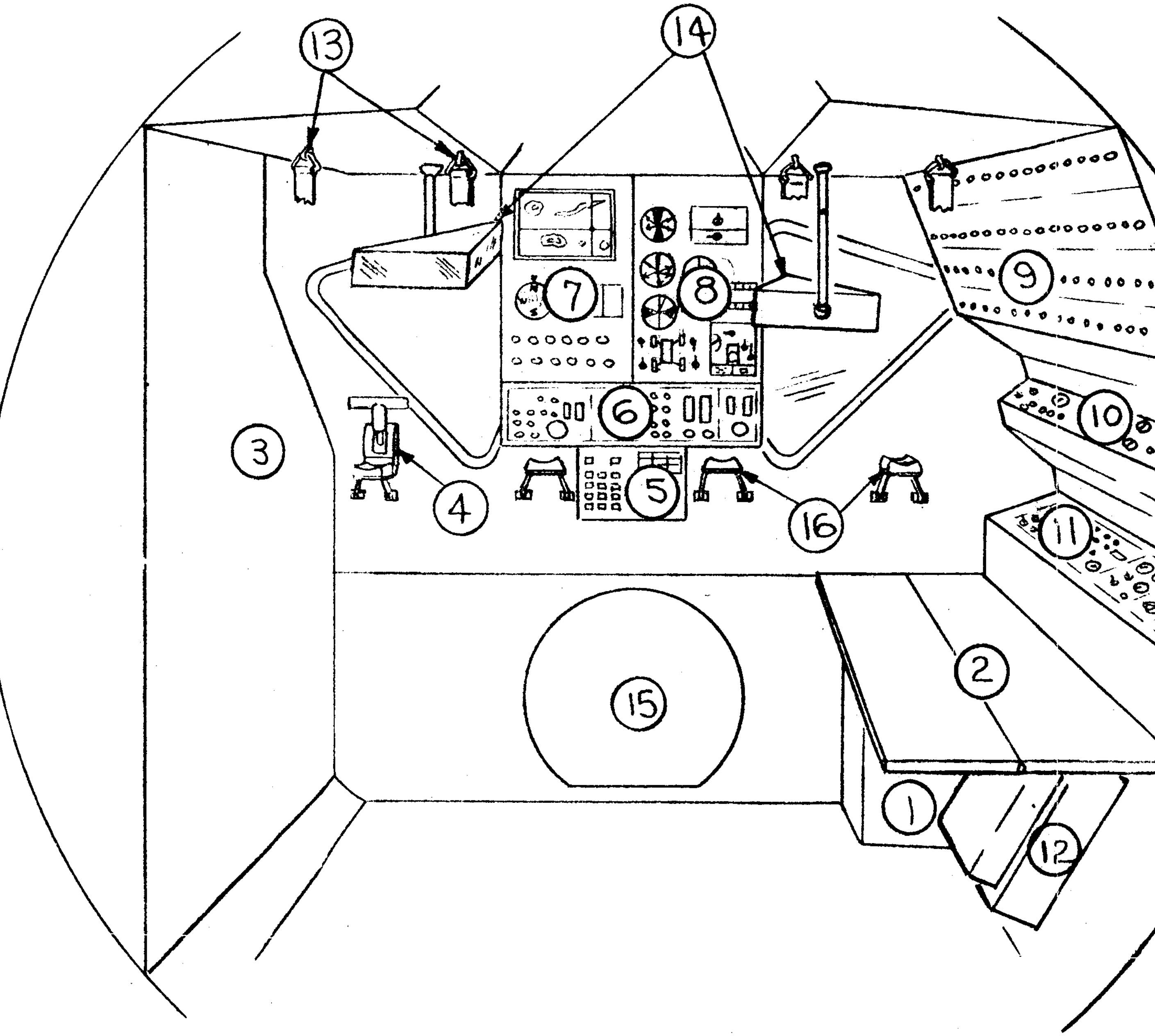
8. CONTROL AND DISPLAY PANEL FOR [illegible] CONTROL, RADAR AND PYROTECHNICS

9. CONTROL AND DISPLAY PANEL FOR AUDIO, COMMUNICATIONS, COMM. ANTENNAS, [illegible] AND FEEDER CONTROL, N & GS

10. SPARE PLSS BACKPACK

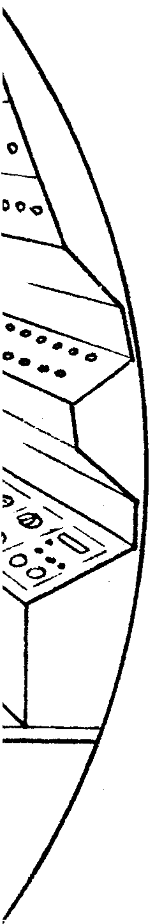
11. FORWARD HATCH

FIGURE 9-[illegible]



CREW STATIONS — CONTROLS & DISPLAYS

MOLEM CONCEPT



1. Storage for Scientific Equipment
2. Work Table
3. Storage Area for LiOH (ECS) Emergency Equipment, Personal Hygiene, Food Preparation Equipment and Miscellaneous
4. Locomotion Control Lever
5. Activity Programmer and Telescope Panel (This Item Presently Exists in LEM)
6. Displays for Lighting, Power Generator and Cryogenic Storage
7. Display Panel for Navigation and Guidance
8. Display Panel for Controls
9. Display Panel for Environmental Control. Communications, Electric Power System, Instrumentation, T.V. Cryogenic Storage
10. Display Panel for IMU Control, Radar, Pyrotechnics
11. Display Panel for Audio, Communications, Comm. Antennas, Coaxial and Feeder Control
12. Spare PLSS Backpack
13. Restraints While Driving (This Item Presently Exists In LEM)
14. Driving Mirror System
15. Forward Hatch (This Item Presently Exists in LEM)
16. Arm Rests (This Item Presently Exists in LEM

FIGURE 5-6

9.12 STRUCTURE SUBSYSTEM

Structural considerations include the load carrying capability of the structural members within a particular network, the materials used for load carrying and non load carrying members, the behavior of these materials in a particular environment, specifically the lunar environment, and the effects of the environment on the candidate materials and on the structural network as a whole.

The majority of load carrying members used in the configurations considered in this study are fabricated from 2219-T87 aluminum alloy. These members have been designed to withstand the various induced inertial and pressure loads. All seals used in the LEM have been assumed to be adequate for the extended mission. This assumption however, may not be valid due to the longer exposure time and hence increased radiation dose levels, and extreme thermal cycling. Also, the crew access hatch seal will be subjected to an increase in cyclic loads due to astronaut egress/ingress.

In addition to the structural considerations mentioned above, a manned vehicle used on the lunar surface must provide adequate protection from micrometeoroid and penetrating radiation bombardment. In each case the structural network must incorporate sufficient material to meet these requirements. To minimize the weight penalty associated with affording micrometeoroid protection, multi-layer wall cross sections utilizing a low density filler material can be used.

Penetrating radiation on the lunar surface is due, mainly, to proton bombardment. The radiation protection requirements can result in a severe weight penalty for manned lunar vehicles if all of the shielding is incorporated in the vehicle structure alone. A method of minimizing the radiation shield weight required is to consider the shielding effect of the vehicle equipment. The determination of the equipment shielding contribution was outside the scope of this report and therefore, was not further considered.

The following subsections discuss the LEM structure and the required structural modifications for conversion to the LEM/S and MOLEM.

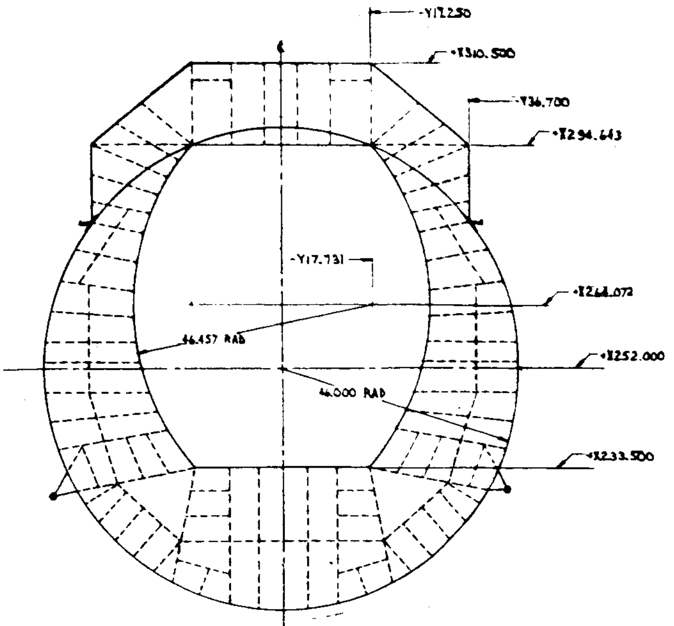
9.12.1 LEM

The LEM structure consists of two main assemblies, i.e., ascent stage structure and descent stage structure. These two assemblies will be discussed in this section.

The Ascent Stage structure is shown in Figure 9-22. The structural members have been utilized to form three main subassemblies, i.e., the crew compartment, the midsection and the aft equipment bay.

The crew compartment consists of a 92 inch diameter circular cylinder approximately 40 inches long. Two inch deep circumferential frames and several longerons are employed for purposes of stiffening the entire crew compartment section. The forward end of the crew compartment is closed by the stiffened face subassembly shown in Figure 9-22. Contained within the face subassembly is an egress/ingress hatch and two viewing windows. The 2 inch thick crew compartment wall cross-section consists of two layers of aluminum (.03 inch inner load carrying sheet and .006 inch outer sheet) with a 1/4 inch layer of thermal insulation sandwiched between. The outer bumper sheet is supported from the inner skin by polycarbonate spacers mounted on 12 inch centers. Floor structure has been provided in the crew compartment, which allows for approximately 75 inches (minimum) to 80 inches (maximum) floor to ceiling clearance. The aft end of the crew compartment has a flat circular stiffened bulkhead with an opening in the center for access to the midsection.

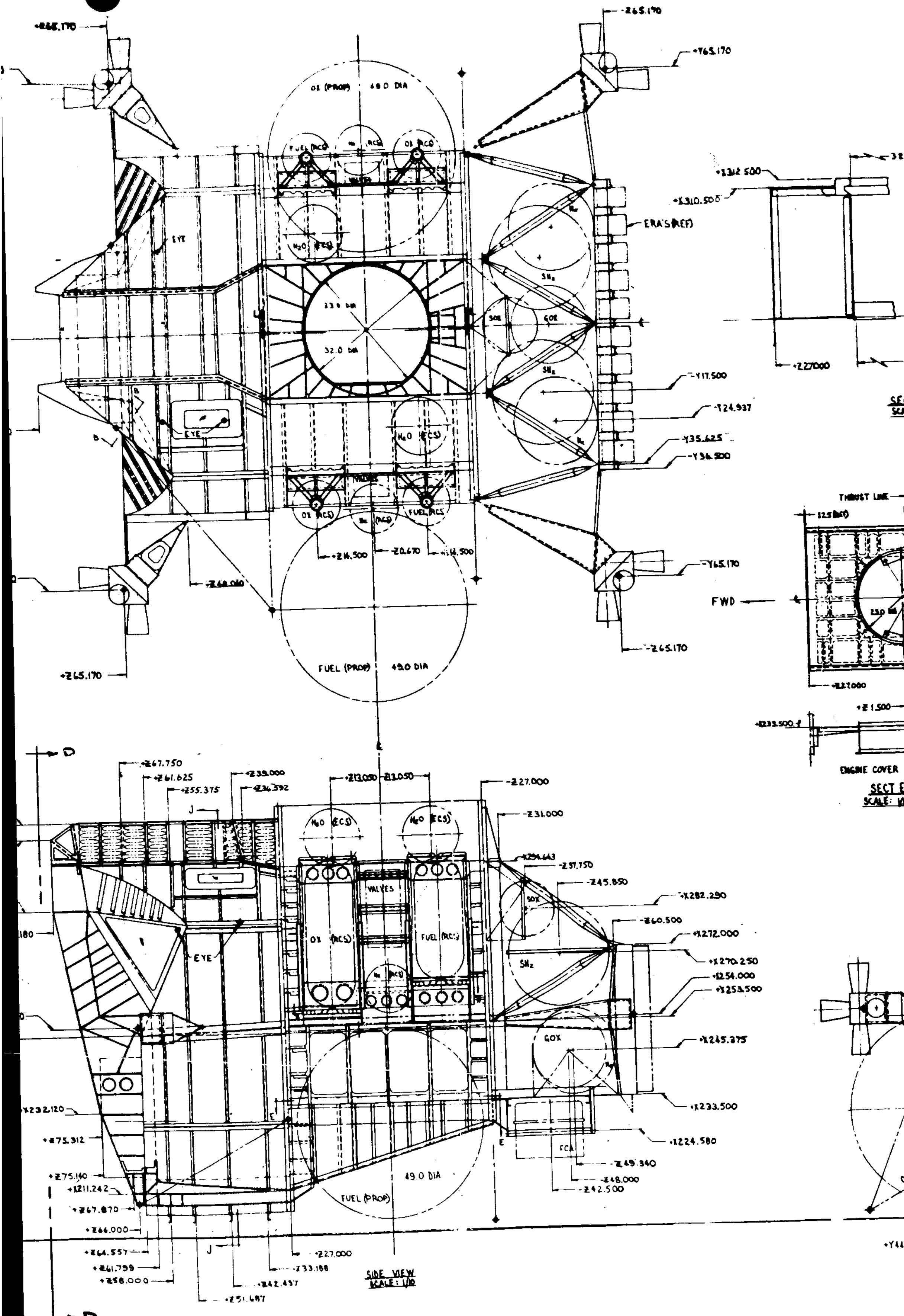
Multi-layer wall construction similar to that used in the crew compartment section is also used in the midsection. The inner side walls are chem-milled circular cylindrical segments with radii of 46.6 inches. These walls are stiffened by circumferential frames approximately ten inches apart. The top of the midsection is made of a machined deck containing the upper docking adapter and reinforcing ring. The bottom is closed with a machined engine support deck. The midsection deck is 18 inches above the crew compartment deck level. This allows 60 inches of floor to ceiling clearance. In addition, an ascent engine cover is mounted to the lower machined deck. The engine cover is 33 inches in diameter and protrudes 20 inches above the midsection floor level. The midsection floor space is approximately 34 inches wide and 54 inches long. The aft end of the midsection is closed by the stiffened bulkhead shown in Figure 9.22.



+Z227.000 BLKD
VIEW LKG AFT
SCALE : 1/10

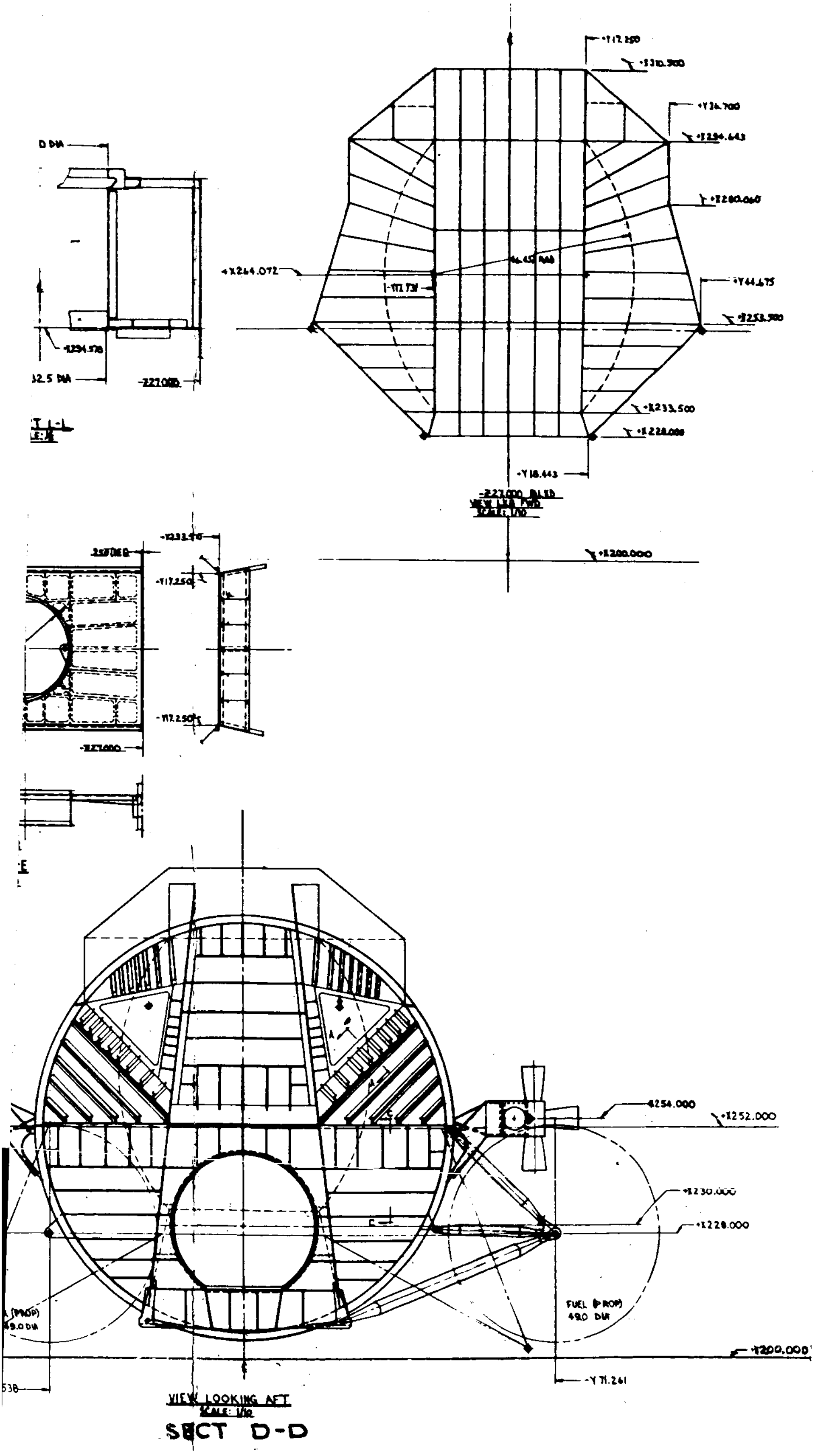
NOTE: THIS FIGURE REPRODUCED FROM REFERENCE 3.

B3-1



LEM ASCENT STAGE STRUCTURAL ARRANG

133-2



EMENT

FIGURE 9-22

The aft equipment bay consists of an equipment rack and deck cantilevered from the aft midsection bulkhead. Various replaceable electronics components are mounted to cold plates and supported by the equipment rack and deck. Three fuel cell assemblies are also supported from the aft midsection bulkhead below the equipment rack deck. Two cryogenic tanks, two helium tanks and one gaseous oxygen accumulator are also mounted in the aft equipment bay.

The entire ascent stage structural arrangement forming the crew compartment, midsection, aft equipment bay and the ascent engine fuel and oxidizer tanks are covered by a composite thermal shield. This shield consists of multiple layers of NRC-2 insulation and the previously mentioned outer aluminum skin.

Hard points have been provided on the forward crew compartment bulkhead and the midsection aft bulkhead for the inner stage connection. Struts are attached to these hard points and to four hard points on the descent stage. These struts are capable of withstanding the shock loads imposed at lunar touchdown. The structural weights are given in Table 9-20.

9.12.2 LEM Shelter

Two concepts for the extended LEM/S are presented in Figures 9-1 and 9-2. Concept I (Figure 9-1) utilizes existing primary LEM structure, the only significant modifications being removal of the ascent engine cover from the midsection, removal of ascent propellant tanks, and the structural modification necessary for both concepts, to furnish the necessary thermal insulation and micrometeoroid protection.

The single sheet aluminum thickness required for micrometeoroid protection was found to be .35 inches[13]. This thickness was based on a 99% probability of no penetrations in the pressure shell for the six month dormant period, and the fourteen day manned period. The total aluminum thickness was reduced by considering a multi-layer wall cross-section with a low density filler. The cross section chosen consists of an inner and outer aluminum alloy 2219-T87 sheet with one inch of NRC-2 thermal insulation for the filler material. The effectiveness factor for this cross section is .16. The total aluminum thickness therefore, is .16 (.35) = .056 inches. Since the inner skin thickness is .030 the additional material (.026 in.) will be included in the outer bumper sheet. For uniformity, an .030 outer sheet will be added. Increasing the thickness of the outer skin to obtain the required micrometeorite protection minimizes the extent of modification by allowing the primary structure to remain intact.

TABLE 9-20 STRUCTURAL SUBSYSTEM WEIGHTS*

STRUCTURAL SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
STRUCTURE	(1061.3)	(1118.3)	(1146.1)	(1118.3)	(1446.1)	(1118.3)
FRONT FACE	(177.7)		(210.8)		(210.8)	
Skin	48.9		82.0		82.0	
Shielding	18.6		18.6		18.6	
Beams	34.9		34.9		34.9	
Frames	12.6		12.6		12.6	
Trusses & Supports	8.0		8.0		8.0	
Windows (2)	20.0		20.0		20.0	
Hatches (1)	25.0		25.0		25.0	
Joints, Splices & Fasteners	9.7		9.7		9.7	
CABIN	(192.0)		(214.7)		(214.7)	
Skin	34.3		57.0		57.0	
Shielding	18.1		18.1		18.1	
Beams	11.0		11.0		11.0	
Longerons	18.2		18.2		18.2	
Stiffeners	22.5		22.5		22.5	
Frames	17.6		17.6		17.6	
Trusses & Supports	39.4		39.4		39.4	
Decks	8.0		8.0		8.0	
Windows	3.6		3.6		3.6	
Joints, Splices & Fasteners	19.3		19.3		19.3	
MID-SECTION	(513.6)		(542.6)		(542.6)	
Skin	44.0		73.0		73.0	
Shielding	80.9		80.9		80.9	

TABLE 9-20 STRUCTURAL SUBSYSTEM WEIGHTS (cont'd)*

STRUCTURE SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
Bulkheads	94.1		94.1		94.1	
Beams	31.8		31.8		31.8	
Longerons	7.6		7.6		7.6	
Stiffeners	27.1		27.1		27.1	
Frames	31.6		31.6		31.6	
Trusses & Supports	85.8		85.8		85.8	
Decks	67.8		67.8		67.8	
Hatches	25.0		25.0		25.0	
Joints, Splices & Fasteners	17.9		17.9		17.9	
Aft Equipment Bay	(178.0)		(178.0)		(178.0)	
Shielding	40.9		40.9		40.9	
Beams	36.8		36.8		36.8	
Frames	14.1		14.1		14.1	
Trusses & Supports	72.6		72.6		72.6	
Decks	7.2		7.2		7.2	
Joints, Splices & Fasteners	6.4		6.4		6.4	
Forward Section (+Z)		(293.3)		(293.3)		(293.3)
Panel-Closure		31.8		31.8		31.8
- Left Hand		17.7		17.7		17.7
- Right Hand		17.7		17.7		17.7
Deck - Upper		7.4		7.4		7.4
- Lower		7.4		7.4		7.4
Equipment Bay - Left		19.2		19.2		19.2
- Right		21.8		21.8		21.8

[redacted]

TABLE 9-20 STRUCTURAL SUBSYSTEM WEIGHTS (cont'd)*

STRUCTURE SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
Shielding		37.9		37.9		37.9
Trusses & Supports		96.8		96.8		96.8
S-IV-B Attach. Fittings		6.0		6.0		6.0
Steps & Grips		11.5		11.5		11.5
Egress Platform		10.0		10.0		10.0
Protective Coating		8.1		8.1		8.1
Left Mid-Section (-Y)		(152.2)		(152.2)		(152.2)
Panel - Closure		30.5		30.5		30.5
- Forward		17.3		17.3		17.3
- Aft		17.0		17.0		17.0
Deck - Upper		7.4		7.4		7.4
- Lower		7.4		7.4		7.4
Shielding		10.0		10.0		10.0
Trusses & Supports		52.7		52.7		52.7
S-IV-B Attach. Fittings		6.0		6.0		6.0
Protective Coating		3.9		3.9		3.9
Center Mid-Section		(94.7)		(94.7)		(94.7)
Panel - Left		18.9		18.9		18.9
- Right		18.9		18.9		18.9
- Forward		18.5		18.5		18.5
- Aft		18.0		18.0		18.0
Trusses & Supports		11.2		11.2		11.2
Joints, Splices & Fasteners		9.2		9.2		9.2
Right Mid-Section (+Y)	20	(152.0)		(152.0)		(152.0)

[redacted]

[redacted]

TABLE 9-20 STRUCTURAL SUBSYSTEM WEIGHTS (cont'd)*

STRUCTURE SUBSYSTEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
Panel - Closure		30.5		30.5		30.5
- Forward		17.3		17.3		17.3
- Aft		16.8		16.8		16.8
Deck - Upper		7.4		7.4		7.4
- Lower		7.4		7.4		7.4
Shielding		10.0		10.0		10.0
Trusses & Supports		52.7		52.7		52.7
S-IV-B Attach. Fittings		6.0		6.0		6.0
Protective Coating		3.9		3.9		3.9
Aft Section (-Z)		(248.6)		(248.6)		(248.6)
Panel - Closure		30.6		30.6		30.6
- Left		16.7		16.7		16.7
- Right		16.7		16.7		16.7
Deck - Upper		7.4		7.4		7.4
- Lower		7.4		7.4		7.4
Equipment Bay - Left		19.2		19.2		19.2
- Right		21.8		21.8		21.8
Shielding		37.9		37.9		37.9
Trusses & Supports		76.8		76.8		76.8
S-IV-B Attach. Fittings		6.0		6.0		6.0
Protective Coating		8.1		8.1		8.1
Base Heat Shield		(134.5)		(134.5)		(134.5)
Miscellaneous		(43.0)		(43.0)		(43.0)
Trusses & Supports		14.0		14.0		14.0

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

TABLE 9-20 STRUCTURAL SUBSYSTEM WEIGHTS (cont'd)*

STRUCTURE SUBSYSTEM	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
Separation System		29.0		29.0		29.0
Chassis					(300.0)	

The one inch thick NRC-2 thermal insulation considered for use in the LEM/S has a density of 2.2 lbs/ft^3 and a thermal conductivity of .000052 $\frac{BTU - ft}{hr - ft^2 - ^oR}$. The insulation density used on the LEM was calculated to be approximately 6.5 lbs/ft^3. It was therefore, considered feasible to increase the LEM/S insulation thickness without increasing the shield weight over that of the LEM.

The radiation dose level inside the LEM/S cabin is not to exceed 250 rads while on the lunar surface. To insure that this maximum does level is not exceeded the required thickness for shielding is .284 inches of aluminum[14]. Further studies in the area of radiation shielding are expected to utilize cabin equipment and skin to maintain the radiation dose level at, or below 250 rads. It is likely then, that additional shielding material will be required only in specific areas rather than for the entire structure. Therefore, for the purpose of this report no additional shielding will be considered necessary for the LEM shelter.

The LEM/S structural weight listed in Table 9-20 is applicable to Concept I (Figure 9-1). This concept is the preferred LEM/S configuration from the standpoint of minimum modification. However, for housing two men for 14 days it is the least desirable configuration.

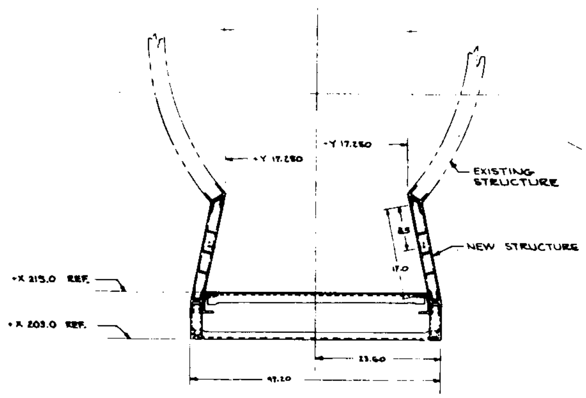
Concept II (Figure 9-2) has increased the standing room floor space from 16.7 ft^2 to 29.7 ft^2. As shown in Figure 9-23, the use of Concept II involves modification of primary structure and the interruption of primary load paths. This change tends to violate the minimum modification concept. This will require reanalysis of the structure, and a new structural proof test program. The trade-off reduces to that of minimum structural modification versus usable floor space for two men for 14 days.

The weight increase associated with LEM/S Concept II is shown in Figure 9-23.

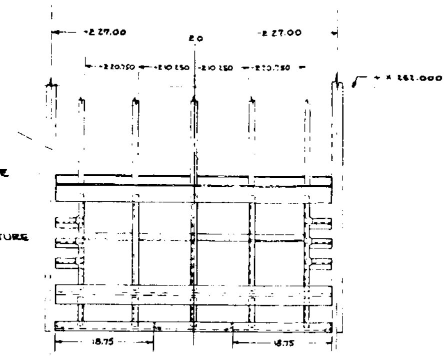
BLANK PAGE

4 3

D

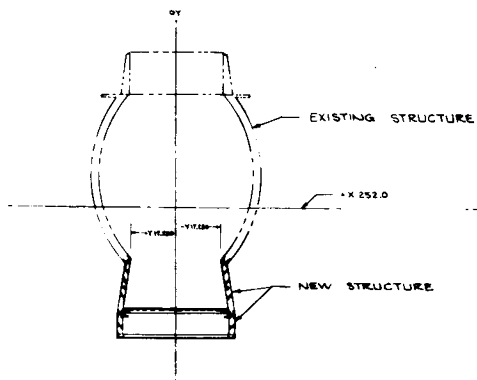


C

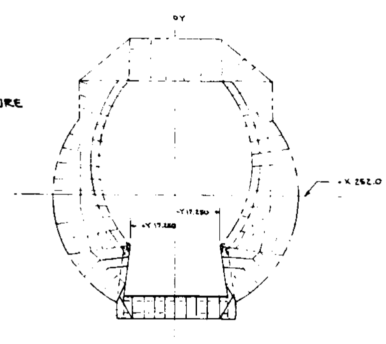


DETAIL I
$\frac{1}{10}$ SIZE

B



B - B

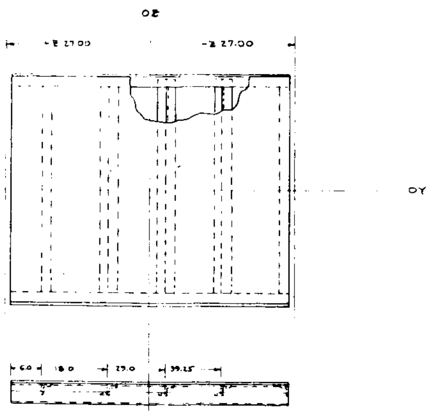


A - A

A

4 3

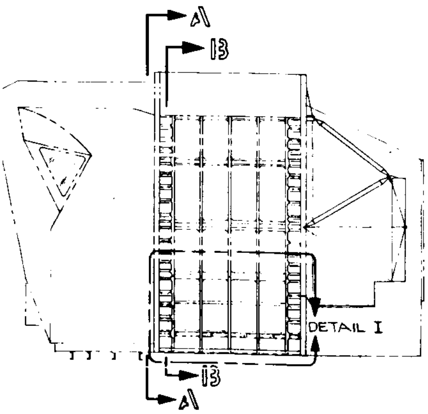
143



DETAIL OF CENTER SECT. FLOOR
$\frac{1}{10}$ SIZE

SKIN	6.0
SHIELDING	4.0
LONGERONS	5.0
STIFFNERS	10.0
FRAMES	5.0
DECK	10.0
ITEM	WEIGHT~Lbs

STRUCTURE ADDED TO LEM ASCENT STAGE



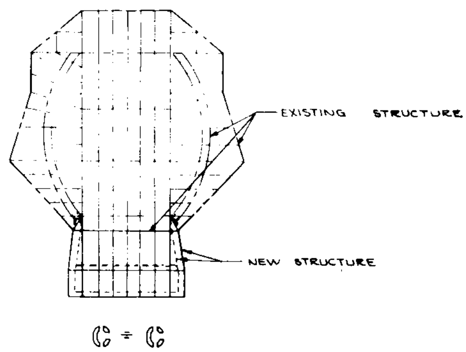


FIGURE 9-23

LIST OF MATERIAL

SEE ENGINEERING RECORDS

11-FEB-65

LEM SHELTER CONCEPT II STRUCTURAL MODIFICATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-8

9.12.3 MOLEM

The LEM structure was not well defined for this study and this limited the structural analyses which could be performed to isolated areas. The total cabin skin thickness was resized to .060 inches to provide the required meteorite protection for the MOLEM's six month dormant period [13]. This increase was accomplished by leaving the inner skin. 030 inches and changing the outer skin from .006 inches to .030 inches. The 2.0 in. spacing between skins was not changed. Also, the wheel loads were established and a loads and stress analyses performed for the wheel arms and the chassis. The resulting weights for the cabin skin and chassis is shown in Table 9-20. The wheel arm weights and related mobility equipment weights are given in Table 9-22, Section 9.14.3.

The addition of mobility to the LEM ascent stage cannot be accomplished within the definition of minimum modification as given in Section 6.0. The mobility loadings on the LEM structure will require extensive structural reanalysis and an extensive proof testing program. The magnitude of the static loading and resulting stresses during lunar locomotion are not expected to exceed the LEM's loads and stresses during the LEM mission and in particular upon lunar landing. However, the dynamic loadings due to the 375 kilometer, 71.2 hour traverse, including obstacle negotiation accelerations, will necessitate a major revision in testing programs. Cyclic loading and fatigue life will become important design considerations particularly upon the welded cabin structure including the bulkheads to which the mobility loads must be transferred. The effects of the dynamic loadings on the integrity of the pressure vessel can be predicted only after extensive reanalysis including the results of a mobility testing program.

The structural weights for MOLEM are tabulated in Table 9-20. The only changes made include the added outer skin weight for the MOLEM cabin of 84.8 pounds and the added chassis weight of 300 pounds.

9.13 TIEDOWN, LEVELING AND UNLOADING SUBSYSTEM

The attachment, or tiedown, of the LEM ascent stage, the LEM/S and the MOLEM to the descent stage will be discussed in this section. In addition, unloading of the ascent stage payload, or a portion thereof, to the lunar surface, and payload leveling will also be discussed in this section.

9.13.1 LEM

The LEM ascent stage is attached to the descent stage through four struts to the aft midsection bulkhead and through two small trusses to the forward crew compartment face. These struts and trusses are attached to the transverse beams of the descent stage at four points. The LEM tiedown structure can be seen in Figure 3-2.

Unloading and leveling are not required for LEM.

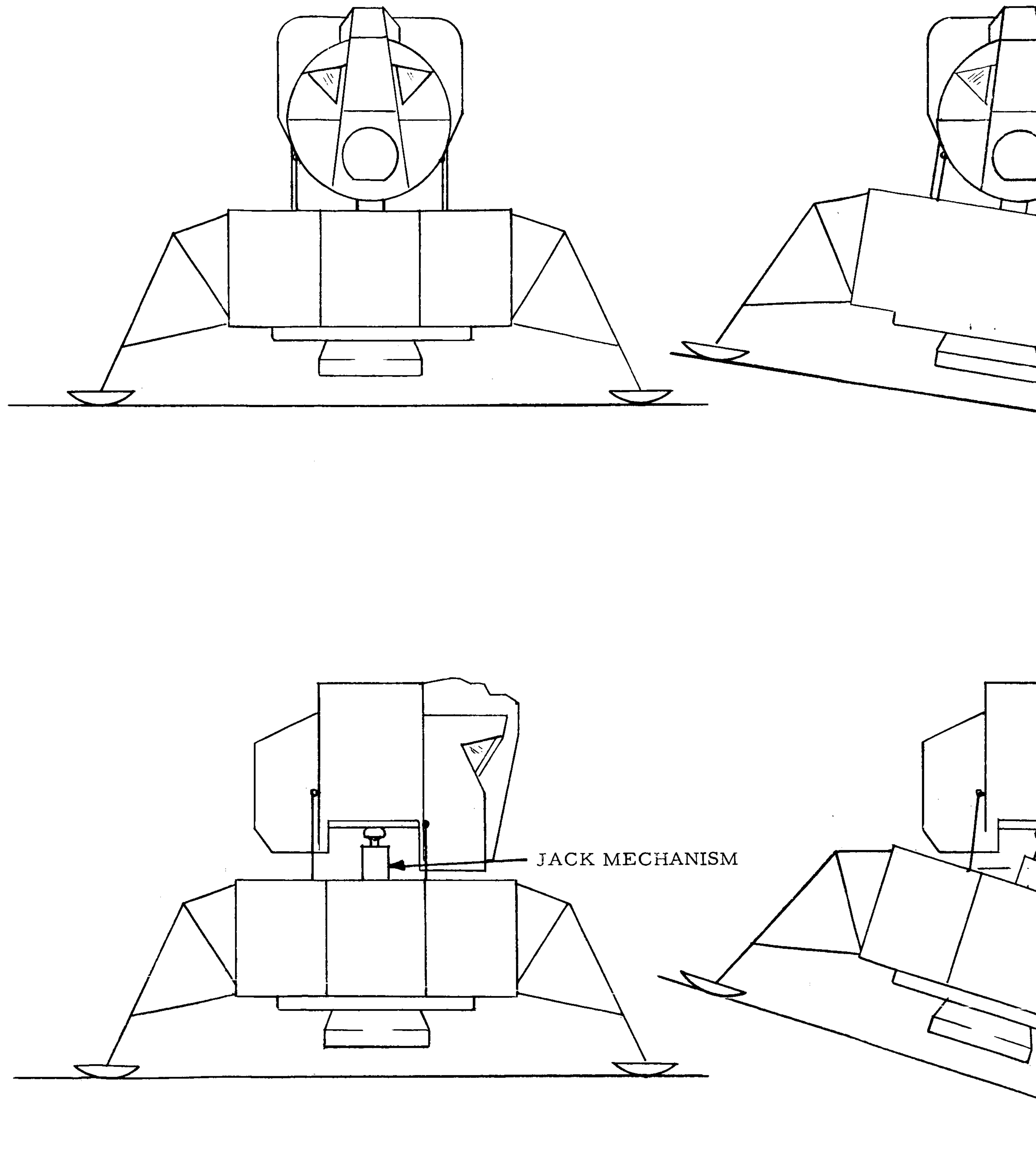
The LEM tiedown system weights are listed under Structural weights in Table 9-20, and will not be repeated in this section.

9.13.2 LEM Shelter

The LEM/S utilizes the same tiedown structure used in the existing LEM. The LEM/S tiedown weights are listed under Structural weights (Table 9-20) and will not be listed in this section.

Since the LEM/S will be occupied for 14 days on the lunar surface and the possiblity of landing on a lunar slope exists, it appears desirable to incorporate a shelter leveling device. This would enable the crewmen to perform their duties without hindrance due to a sloping shelter floor.

The leveling concept developed for the LEM/S (Fig. 9-24) utilizes a jacking mechanism and four cable reel assemblies (attitude control cables). Should the LEM/S be tilted after landing on the lunar surface the tiedown structure attachment to the descent stage can be released, the jack mechanism will raise the LEM shelter from the descent stage for clearance, and the attitude control cables will take in or play out cable as required to obtain a level cabin attitude. Once this is accomplished the attitude control cable reels can be locked. It is assumed that the maximum inclination from the horizontal is 18° as shown in Figure 9-24.



LEM SHELTER LEVELING CONCEPT

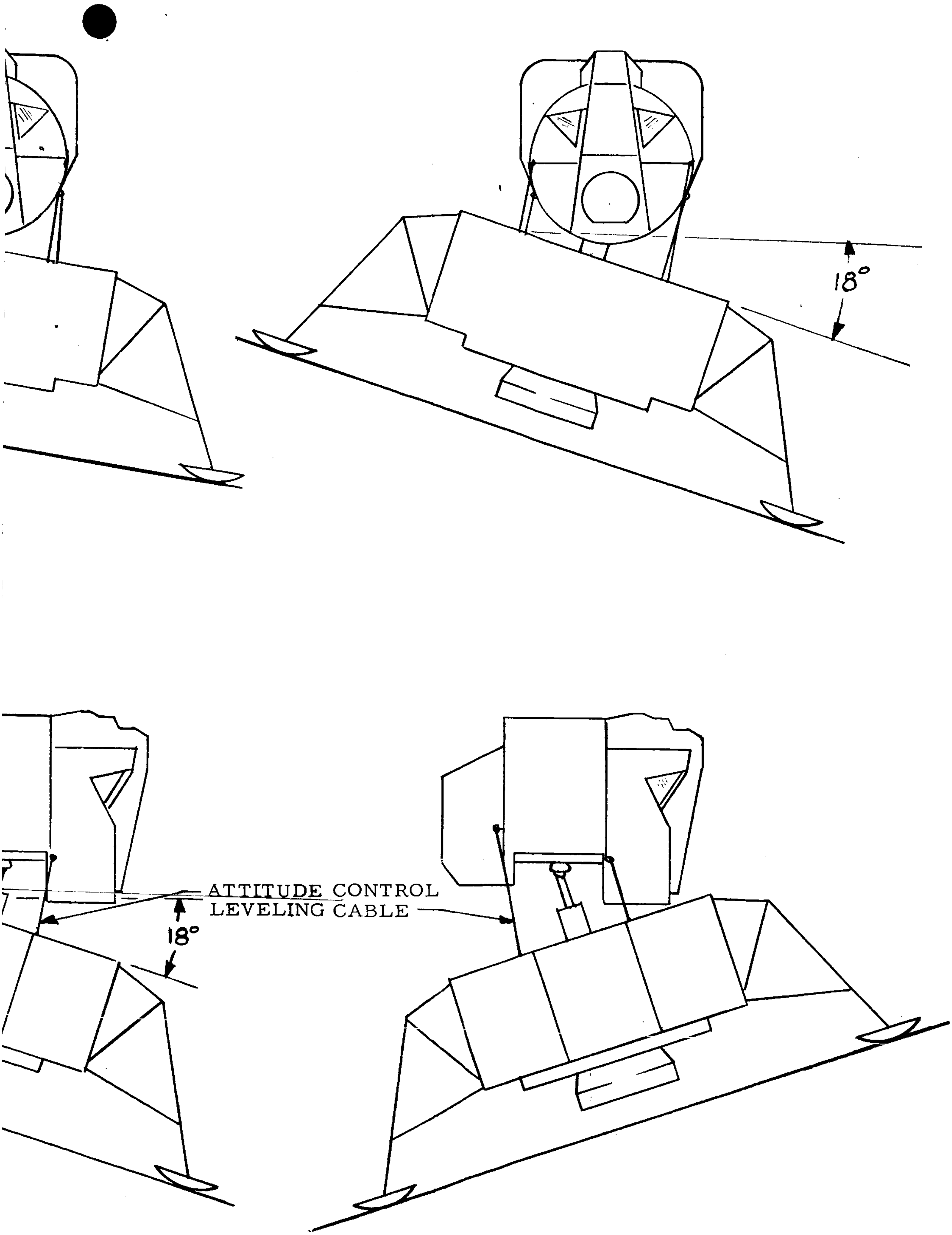


FIGURE 9-24

No appreciable change in LEM structure is considered necessary to incorporate the leveling concept. The jacking mechanism imparts loads to the ascent engine support deck which is capable of withstanding lunar launch loads. The attitude control cables attach to the LEM structural bulkheads at Stations Z27 and -Z27. The cable attach points are in line with bulkhead stiffeners, and the imposed leveling loads are not considered to be large enough to warrant any significant change to the bulkhead structure.

Once leveled, the cabin would be supported by the jack and cables. The jack would supply the necessary upward support reaction while the cables could furnish the necessary downward support reaction. This would subject part of the cabin to cantilever type loads. However, as stated previously the cabin is subjected to more severe loads during lunar launch and should therefore, have adequate structural integrity to withstand the leveling loads.

To accomplish automatic leveling of the LEM/S the attitude control cable reels could receive command signals from the Control Electronics Section (CES) of the SCS. The LEM/S attitude could be sensed by the N&GS, the attitude errors converted by the SCS and the appropriate signals transmitted to the attitude control cable reels.

The weight of the leveling system is given in Table 9-21.

Since the LEM/S payload includes the LSSM, a mechanism for unloading to the lunar surface must be provided. Also, the LSSM must be secured to the descent stage for shipment to the lunar surface.

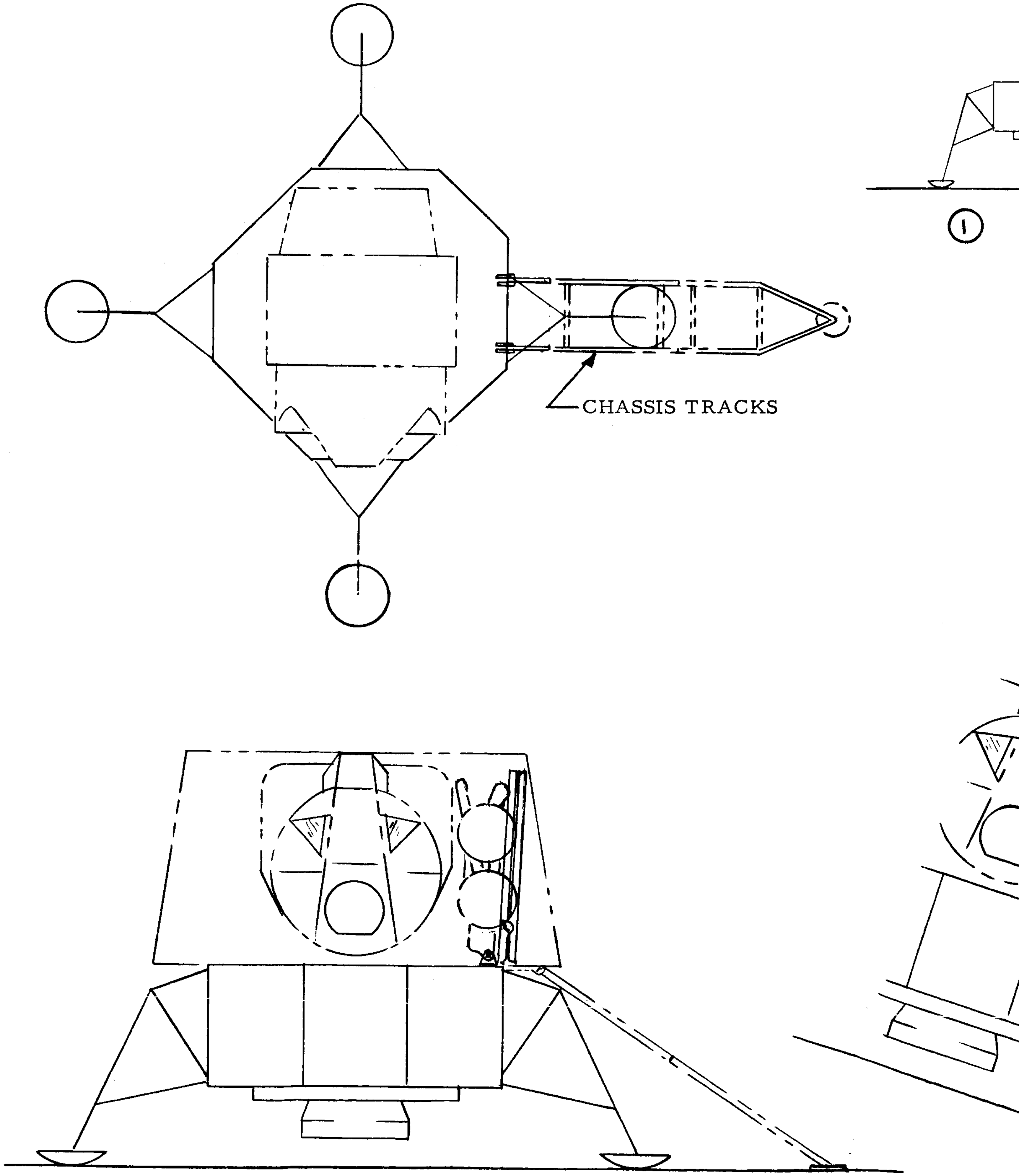
The LSSM tiedown structure consists of two brackets attached to the descent stage primary structure and two support struts attached to the LEM/S bulkheads Z27 and -Z27. This structure is attached to the LSSM chassis as shown in Figure 9-32.

The LSSM unloading system consists of folded chassis tracks, operated by a drive mechanism at the track pivot points (Figure 9-25). The payload ~~envelope allowed approximately 200 inches of track to be~~ stored. LEM/S stability is not considered to represent a significant problem due to the lesser weight of the LSSM. The unloading angle may prove to be a stability problem for the LSSM, however restraining cables could be added if necessary.

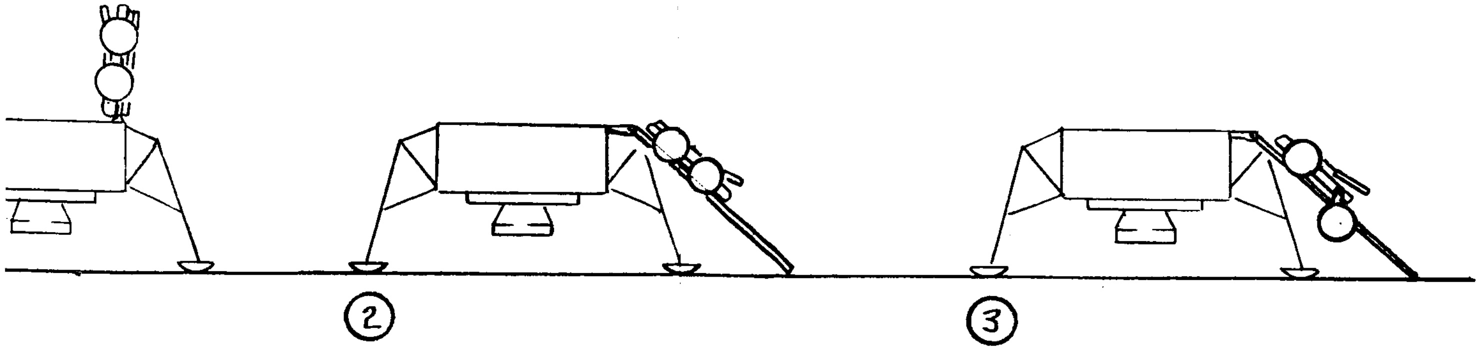
The unloading system weight is given in Table 9-21.

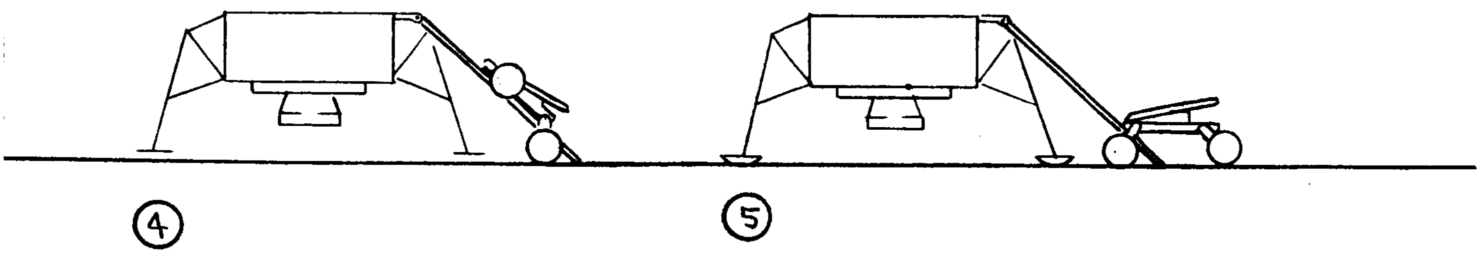
TABLE 9-21 TIEDOWN, LEVELING AND UNLOADING SUBSYSTEM WEIGHTS

TIEDOWN LEVELING AND UNLOADING SUBSYSTEM WEIGHTS	WEIGHT - POUNDS					
ITEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
TIEDOWN			(17)			
LEVELING			(110)			
Jack			80			
Cable & Reel			20			
Misc			10			
UNLOADING			(100)		(500.0)	
Tracks			65.0		150.0	
Turntable					300.0	
Power Supply and Electronic Equipment			20.0		35.0	
Manual Provisions			15.0		15.0	
Total			(227)		(500)	

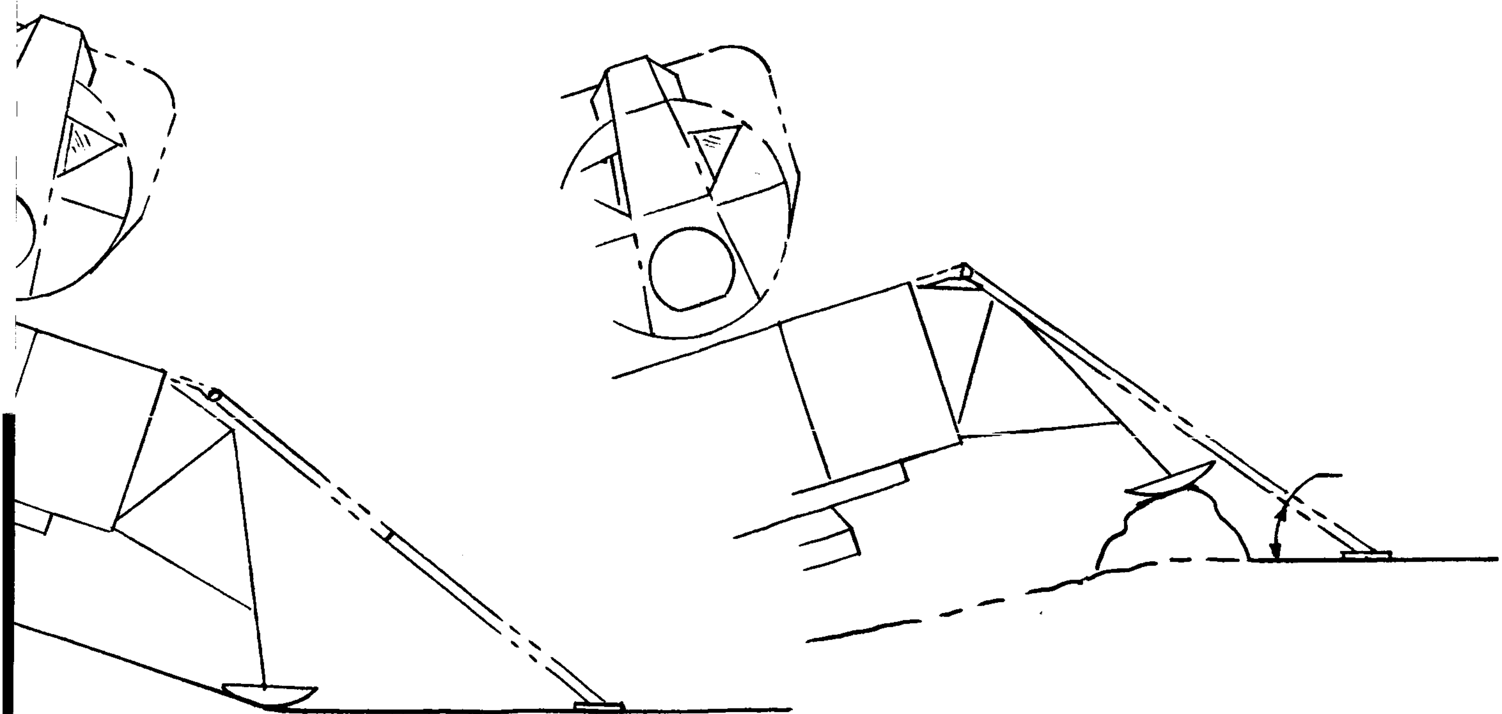


LSSM UNLOAD





UNLOADING SEQUENCE



ING CONCEPT

FIGURE 9-25

9.13.3 Unloading of MOLEM

The details of the MOLEM unloading equipment are shown in Figure 9-26. Chassis tracks have been added for the unloading operation along with an integral bearing turntable to provide 0 - 360° azimuth unloading capability. The unloading operation will commence immediately upon arrival of MOLEM at the lunar surface. The operation is automated and is accomplished by the commands of the remote control Earth station. In the event of failure in the automated equipment a manual unloading capability will be incorporated for use, upon arrival, by the astronaut crew.

The weight for the unloading equipment is shown in Table 9-21 to be 500 pounds. This total includes an allocation for the associated remote control electronic equipment and the battery power supply. The batteries supply power for the motors used to extend the tracks and tow MOLEM off the deck of the descent stage. The batteries are also used to allow creep driving the MOLEM wheel drive motors permitting MOLEM to be driven a safe distance from the descent stage.

A previous study[15] made for unloading systems provides further details including the equipment weight breakdowns, stability considerations track lengths, and unloading sequences.

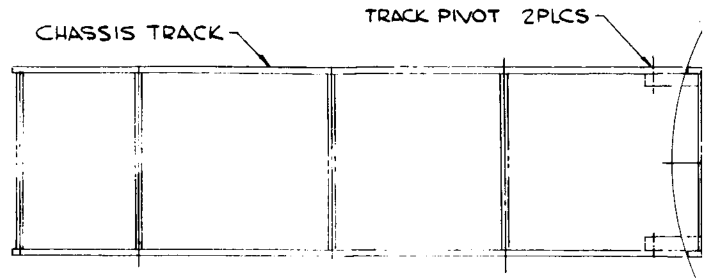
The existing LEM tiedown system will not be changed for the MOLEM application. The same pyrotechnic release assemblies used at the time of lunar launch of the LEM/A will be assumed capable of accomplishing the freeing of MOLEM from the descent stage.

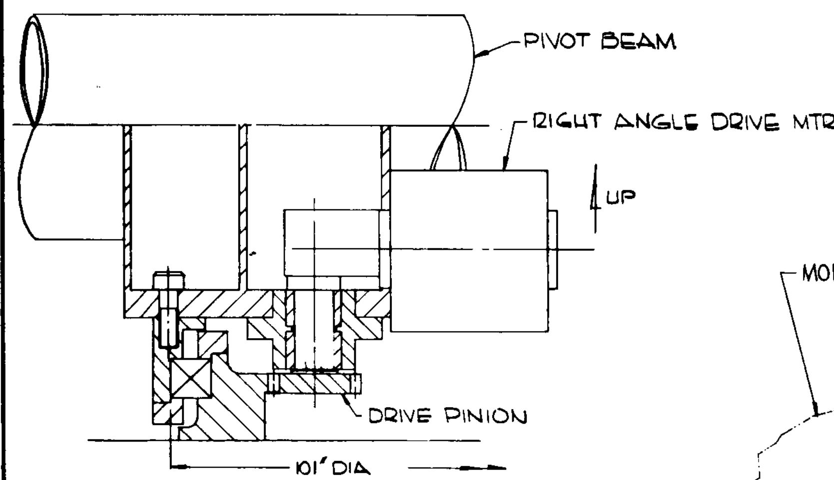
The unloading sequence is as follows:

- Erect MOLEM antennas to allow receipt of Earth signals.
- Free MOLEM from descent stage by deploying tiedown struts.
- With aid of turntable MOLEM is rotated to desired unloading direction.
- Tracks are extended using cable-pulley system and MOLEM is towed off the descent stage to lunar surface.

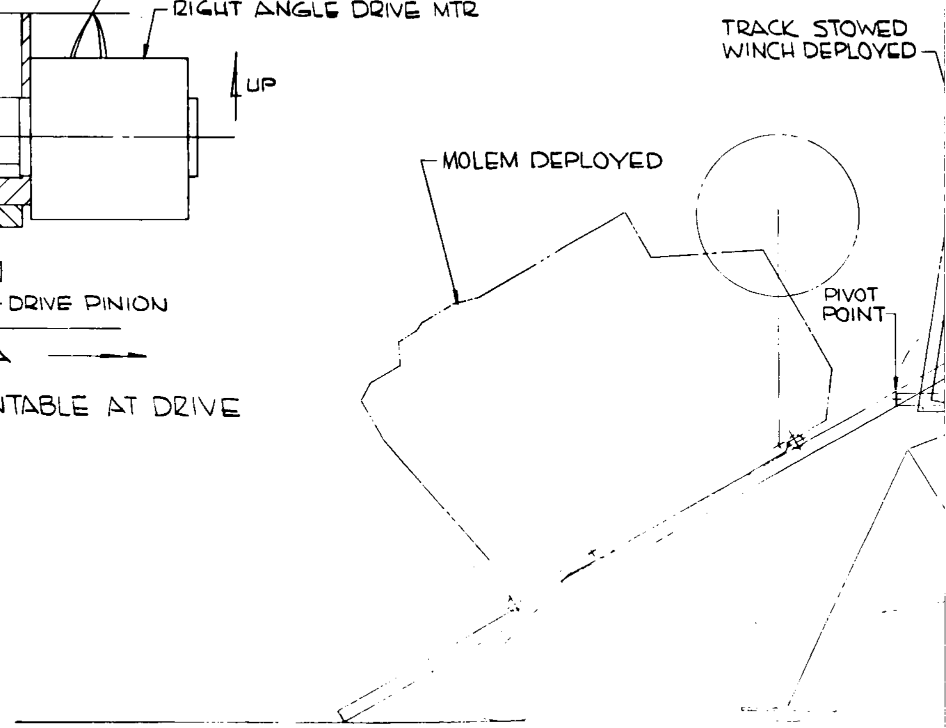
Leveling provisions for MOLEM were not required in this study and were therefore not considered.

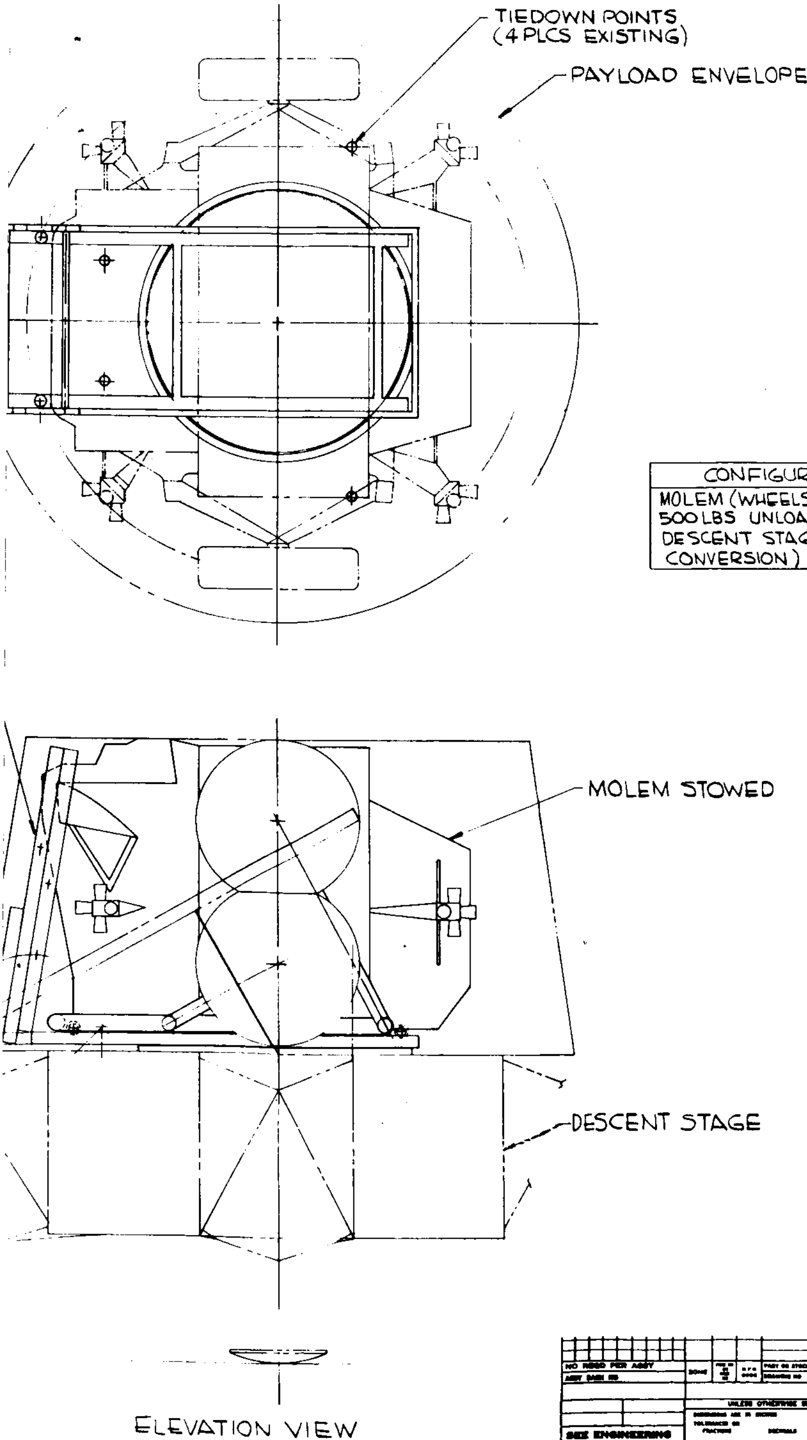
BLANK PAGE 154





SECTION THRU TURNTABLE AT DRIVE
SCALE 1/1





ELEVATION VIEW

CONFIGURATION	WEIGHTS POUNDS	CG COORDINATES INCHES X	Y	Z
MOLEM (WHEELS FOLDED, INCLUDES 500 LBS UNLOADING EQUIPMENT) DESCENT STAGE (MOLEM CONVERSION)				

FIGURE S-26

LIST OF MATERIAL

360° UNLOADING & TIEDOWN SYSTEM MOLEM CONCEPT

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-9

SCALE 1/20

9.14 MOBILITY SUBSYSTEM

No mobility system has been incorporated in the LEM/S module. However, mobility aids considered for the LEM/S include the LSSM and/or the LFV. Provisions have been made for allowing installation of the LSSM and LFV with the LEM/S in order to provide both shelter and mobility with one payload.

A study has been completed for the addition of mobility directly to LEM stage. Of the many methods of accomplishing the LEM mobility function including; rocket propulsion, wheels, tracks, etc., the wheeled vehicle approach was decided to be the most practicable. The MOLEM concept shown in this report is a four wheeled vehicle as established by the study restraints given in Section 4.0.

9.14.1 LEM

The existing LEM has no provisions for mechanized lunar surface mobility. Therefore, no further discussion is considered necessary.

9.14.2 LEM/S

The LEM/S mobility aid is provided by the LSSM or LFV. For this study it has been assumed that the LSSM would be used as the LEM/S supplemental payload.

The LSSM[8] provides the LEM/S crew with lunar traverse capability within a 5 mile (8 km) radius of the LEM/S. This vehicle has been discussed in Section 7.4.

9.14.3 Mobility Requirements for MOLEM

An initial restraint on this study, (see Section 4.0) was to consider four wheeled vehicles only for the lunar surface locomotion studies. The mobility subsystem necessary to provide locomotion capability for the MOLEM vehicle include the following assemblies:

- Traction Assembly
- Drive Assembly
- Steering Assembly
- Braking Assembly
- Wheel Suspension Assembly

The weight tabulation for the mobility subsystem is shown in Table 9-22 to be 1,026 pounds. Figures 9-27 and 9-28 show the details for the mobility assemblies. Each assembly is further discussed below. The MOLEM Earth weight was assumed to be 10,000 pounds for the mobility study.

9.14.3.1 Traction Assembly - The ELMS[7] model was used to define the characteristics of the lunar surface. The lunar soil bearing strength was assumed to be 1.0 psi and this value effectively sized the wheel footprint area. The required wheel footprint area of 417 square inches is obtained by dividing the 10,000 pound MOLEM Earth weight by 6 (reduced lunar gravity) times 4, or 24.

The diameter and width of the wheels was limited by the payload envelope and by the RCS nozzles as shown in Figure 7-3 and discussed in Section 7.3. Two different wheel configurations are shown in Figures 9-27 and 9-28. A 60 inch diameter wheel, 15 inches wide, is shown in Figure 9-27 and a 75 inch diameter wheel, 12 inches wide, is depicted in Figure 9-28. The weights and performance studies for the mobility subsystem is based upon the use of the 60 inch diameter wheel.

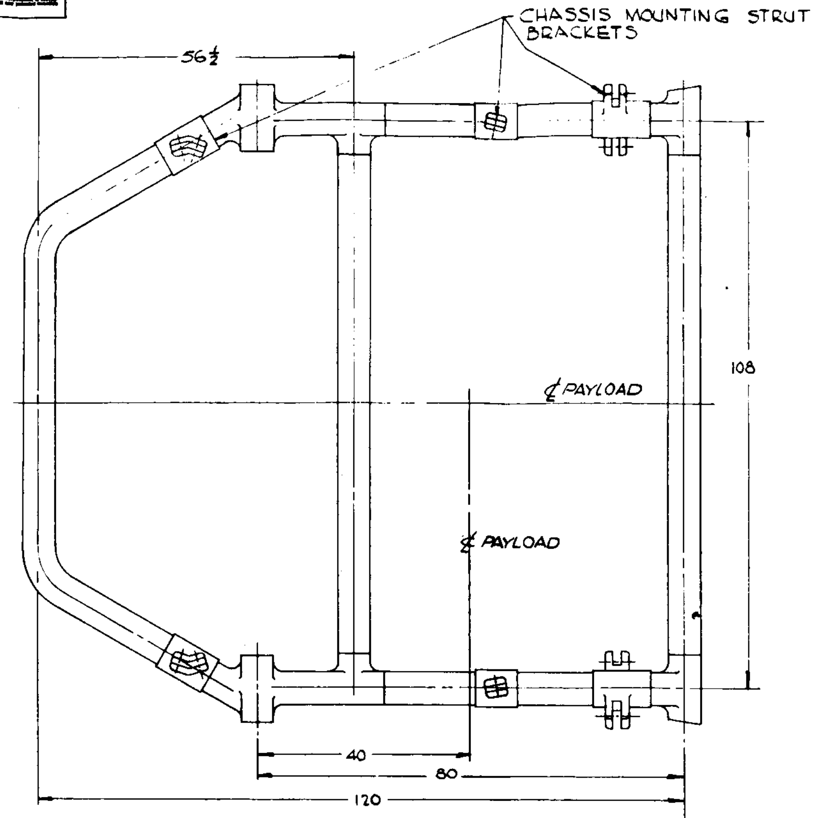
The selected wheels are metalastic flexible circular wheels. The assumed wheel static deflection for the 60 inch diameter wheel was 3 inches resulting in a footprint area of 392.3 square inches and a ground pressure of 1.06 psi.

Larger wheels may be incorporated in the existing payload envelope. However, a more complex wheel unfolding motion would then be required in order to clear the RCS nozzles. The nozzle clearance during wheel unfolding is shown in Figure 9-27.

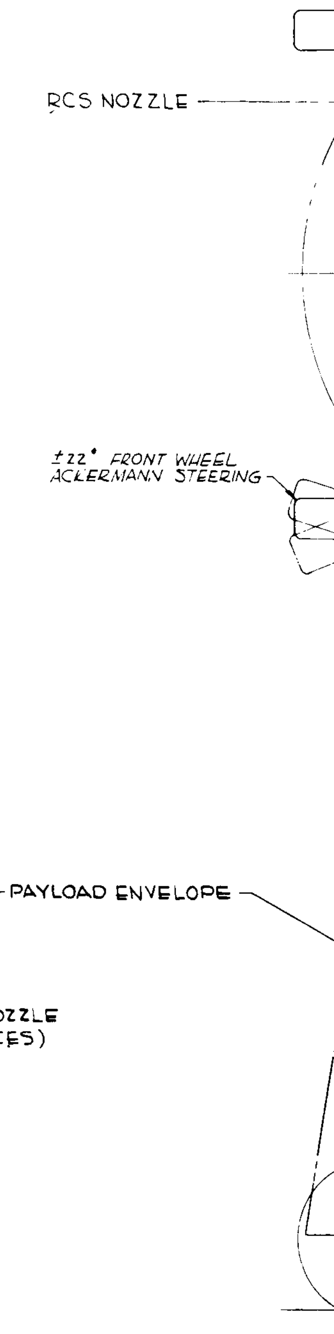
TABLE 9-22 MOBILITY SUBSYSTEM WEIGHTS

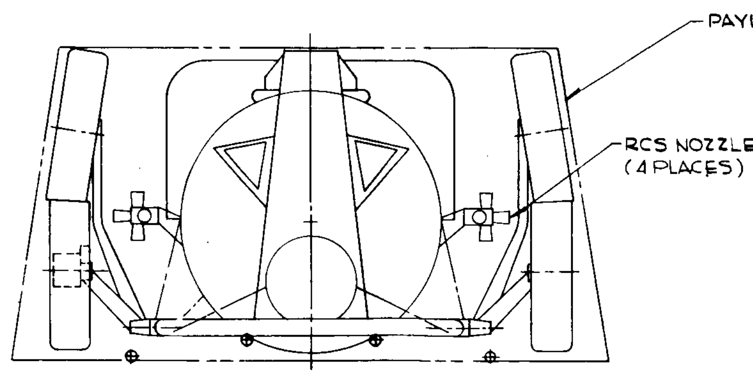
MOBILITY SUBSYSTEM ITEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
MOBILITY					(1026.0)	
Wheels- Metalastic (4)					320.0	
Drive Motors- 1.25 HP (4)					128.0	
Transmission & Gear Reduction (4)					80.0	
Hubs, Bearings, Seal & Misc. (4 sets)					40.0	
Steering Motor & Mechanism (2)					36.0	
Articulated Arms & Actuators					80.0	
Suspension System					300.0	
Disc Brake System (4)					32.0	
Ramp - Ingress/Egress					10.0	

BLANK PAGE 160



CHASSIS DETAIL SCALE 1/10





STEERING GEOMETRY		
STEERING METHOD	WHEEL TURNING ANGLE	WHEEL TURNING RADIUS
ACKERMANN	22°	42.9 FT
SCUFF	0°	13.0 FT

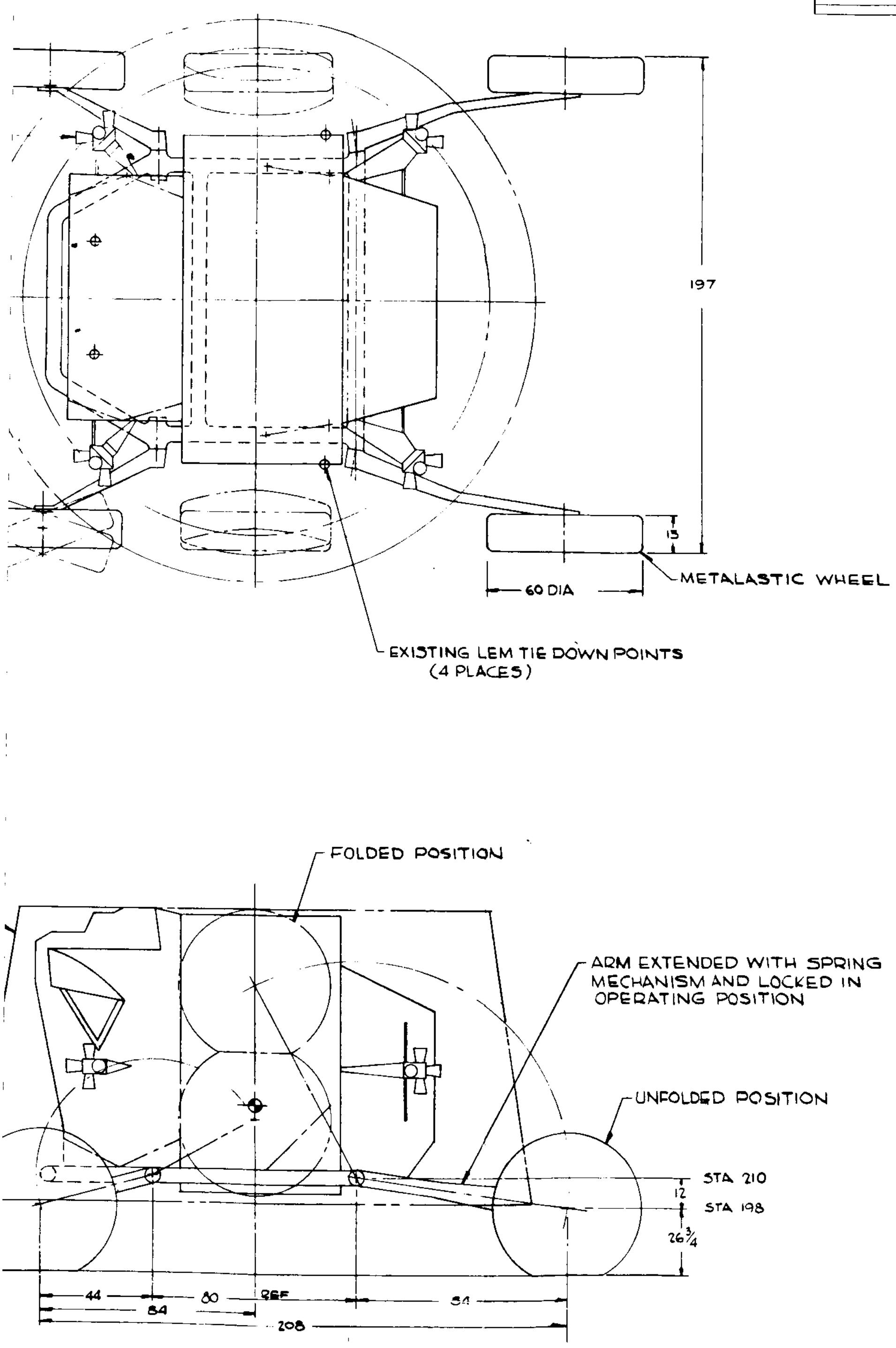


FIGURE 9-27

LIST OF MATERIAL

ORIGINAL DATE OF DRAWING 26FEB65

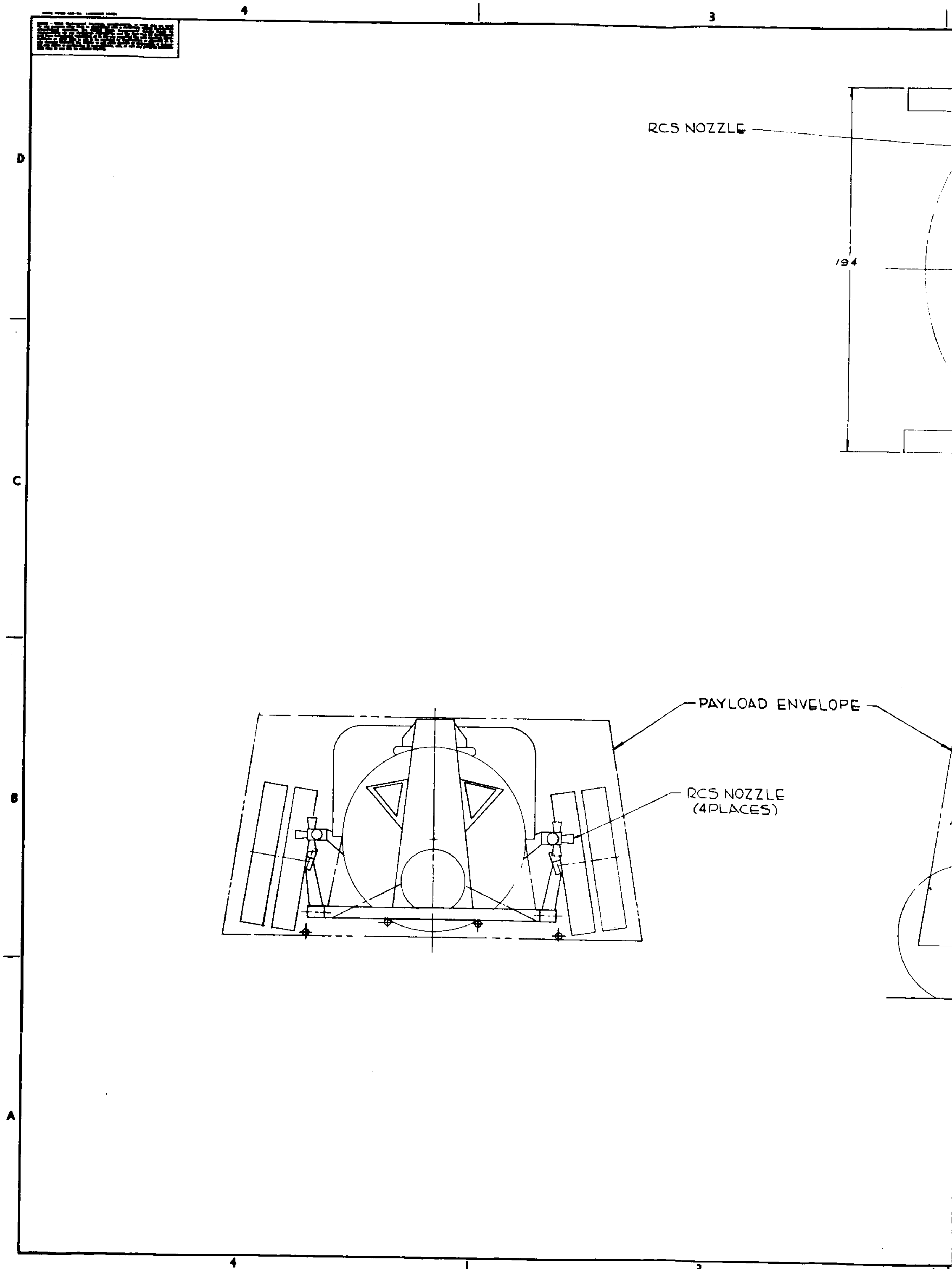
WHEEL UNFOLDING
& MOBILITY CONCEPT
MOLEM

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

SEE ENGINEERING RECORDS

SCALE 1/20

J N-59-10


RCS NOZZLE
194
PAYLOAD ENVELOPE
RCS NOZZLE
(4PLACES)

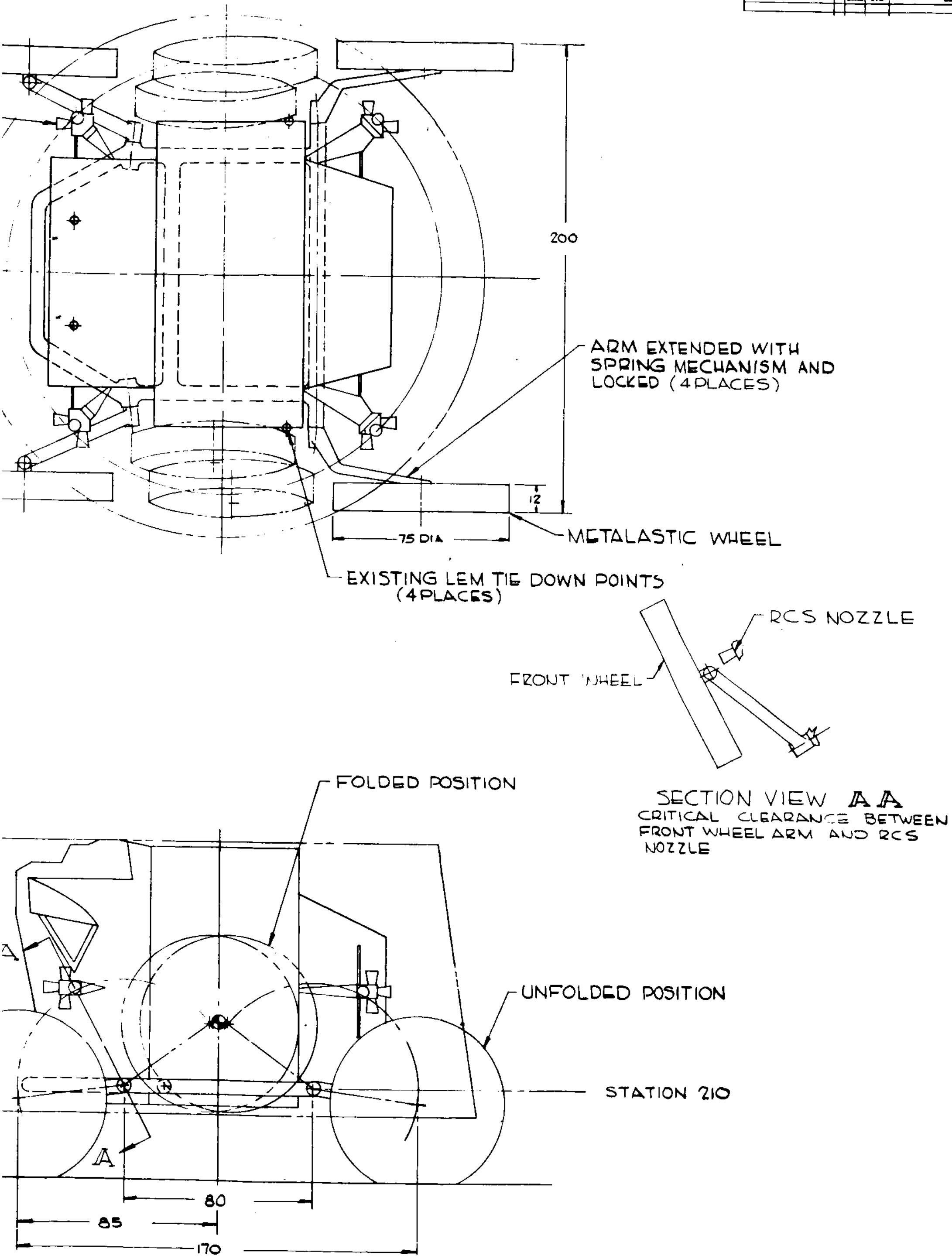


FIGURE 9-28

LIST OF MATERIAL

SEE ENGINEERING RECORDS

MARGS

WHEEL UNFOLDING & MOBILITY CONCEPT MOLEM

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-10

SCALE 1/20

SHEET 2 OF 2

9.14.3.2 Drive Assembly - A self-contained electric drive motor with the required gear reduction unit will be located in the hub of each wheel. The wheel speeds may be adjusted by remotely varying the drive motor voltage and the transmission gear ratio[16].

An analytical evaluation of the MOLEM power requirement indicated each 28 volt D. C. electric motor should have a power capability of 1.1 Kw (1.5 H. P.). The combined efficiency of the electric motor and transmission was assumed to be 72%.

9.14.3.3 Steering Assembly - Two types of steering methods are provided for the MOLEM. Individual steering motors are mounted on the two front wheels to permit Ackermann steering. Also, since individual drive motors are incorporated for each wheel, scuff steering is also provided. The Ackermann steering method will require sychronization of the two front wheel steering motors. With the aid of positive mechanical stops a maximum front wheel turning angle of 22 degrees will provide a 42.9 feet inside turning radius.

Scuff steering is recommended as a backup steering method and it will provide a wheel turning radius of approximately 13 feet. The principal reasons for not recommending scuff steering as the primary method are:

- Excessive power requirement
- Excessive wear and abuse of the wheels

9.14.3.4 Braking Assembly

The primary braking mode will be a mechanical disc brake located at each wheel. The activation of the disc brakes is accomplished by a flexible cable, caliper clamp and an equalizer bar[16].

A secondary braking mode, more effective at higher velocities, is the use of drive motors as generators[17]. When switched to the generator position the force required to drive the motors will retard the wheels and the resultant electrical power will be dissipated as heat.

9.14.3.5 Wheel Suspension Assembly - The wheel suspension assembly includes the articulated wheel arms and independent torsion bars mounted directly to the chassis. One end of the articulated arm is attached to the wheel and the other end to the torsion bar. The articulated motion of the wheel arms, shown in Figures 9-27 and 9-28 occurs only at the time the wheels are unfolded. After unfolding, the arms are locked in the operational position. The unfolding of the wheels is performed with the aid of spring power.

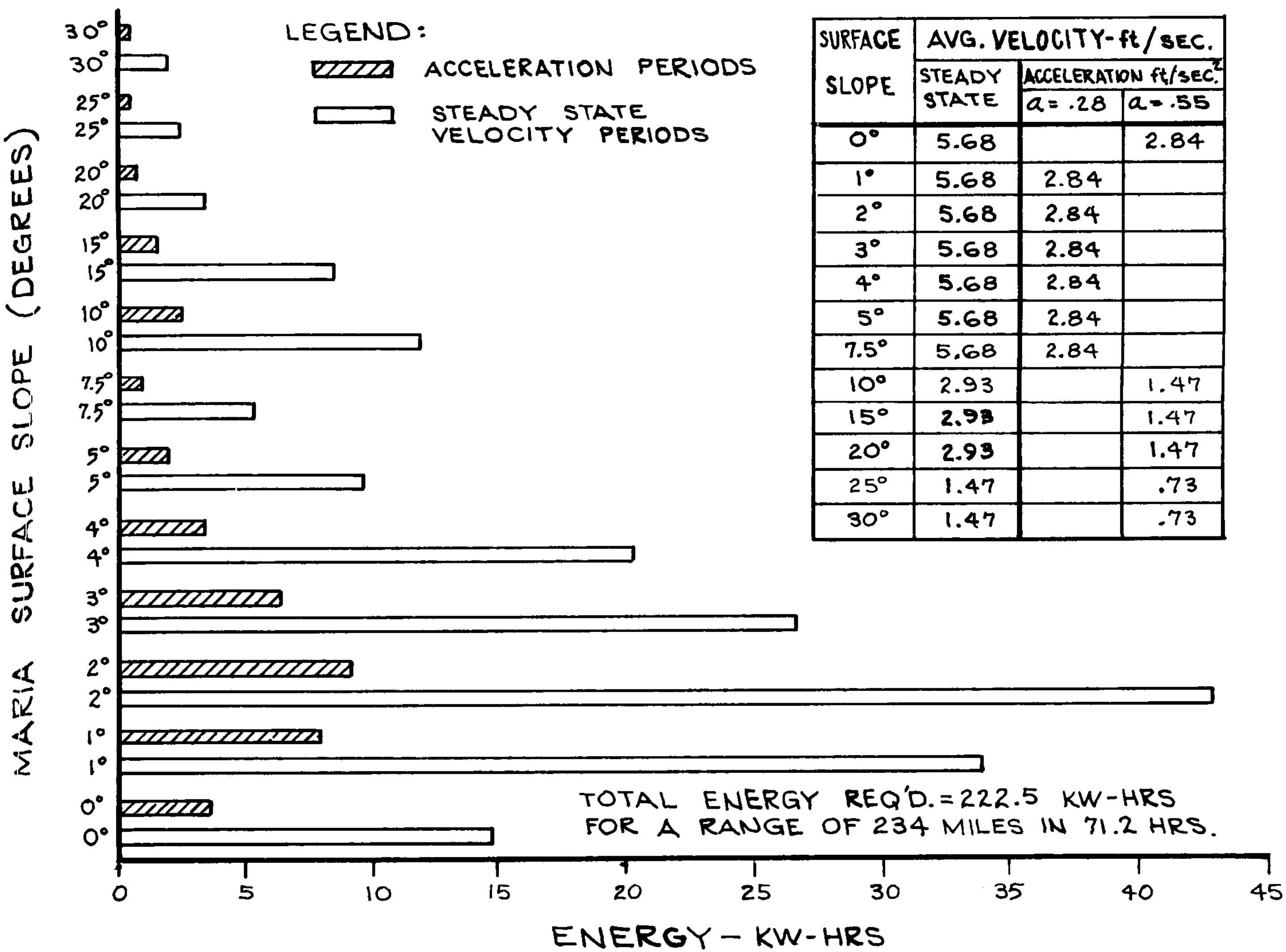
The primary dynamic shock loads will be absorbed by the flexible metal wheels. The independent torsion bars will absorb the secondary shock loadings resulting from obstacles encountered during MOLEM travel[18].

9.14.3.6 Mobility Performance Evaluation - The range of the MOLEM mission was assumed to be 375 kilometers (234 miles) and the total mission driving time was 71.2 hours. A precise traverse was neither specified nor assumed for MOLEM. A lunar maria surface model[7] was used and the resulting percent of total distance traveled on each slope is shown in Table C-1. Ten percent of the total distance is assumed to be devoted to accelerations and decelerations with equal distance and power requirement assumed for both.

The tabular results of performance calculations[19] for the 10,000 pound MOLEM is furnished in Appendix C. The Table shows wheel resistance, total vehicle resistance and vehicle power requirements for steady state velocities on various slopes. Peak power requirements are also shown for varying slopes, velocities and acceleration rates in Table C-1. This data is based upon the use of the 60 inch diameter wheel shown in Figure 9-27 and a wheel deflection of 3 inches.

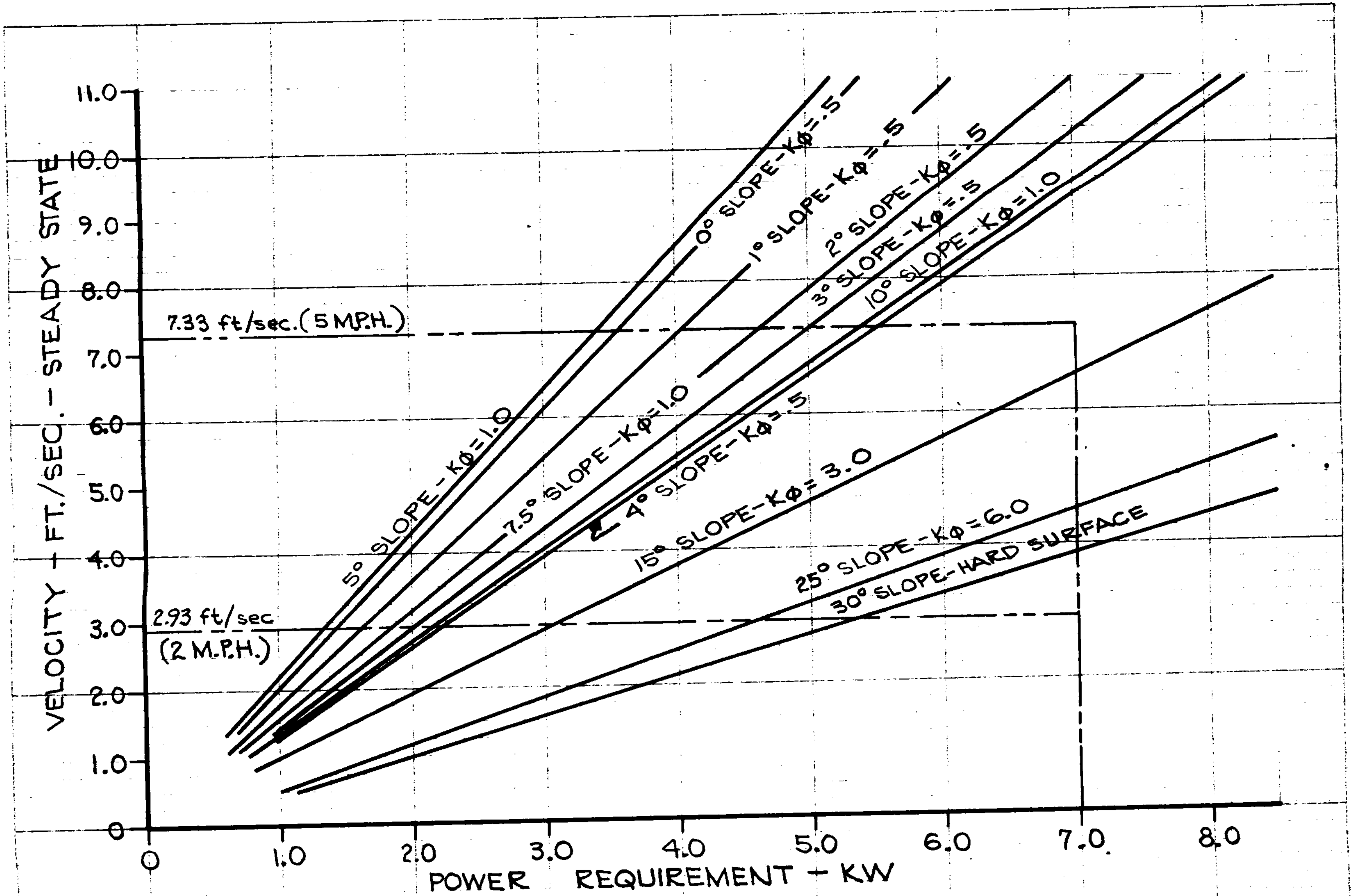
The total mobility energy requirement is shown in Figure 9-29 to be 222.5 kilowatt hours. The energies required are shown for each slope and further divided for each slope into steady state and acceleration phase requirements. The MOLEM power-velocity relationship is shown in Figure 9-30. The power shown is that required to maintain the plotted steady state velocities on the varying slopes. An upper velocity limit of 5 mph is shown along with a steady-state power requirement limit of 7.0 kilowatts. This power value of 7.0 kilowatts is considered to be the upper limit for both the steady state and peak power requirements as stated in Section 9.4.3.

MOLEM ENERGY REQUIREMENTS FOR LOCOMOTION



SURFACE SLOPE	AVG. VELOCITY-ft/sec. STEADY STATE	ACCELERATION ft/sec.² $a = .28$	$a = .55$
0°	5.68		2.84
1°	5.68	2.84	
2°	5.68	2.84	
3°	5.68	2.84	
4°	5.68	2.84	
5°	5.68	2.84	
7.5°	5.68	2.84	
10°	2.93		1.47
15°	2.93		1.47
20°	2.93		1.47
25°	1.47		.73
30°	1.47		.73

FIGURE 9-29



MOLEM POWER-VELOCITY RELATIONSHIP
FOR VARIOUS LUNAR SLOPES
FIGURE 9-30

9.15 INTEGRATED SUBSYSTEMS

The modifications of existing LEM subsystems considered necessary for use in the LEM/S and MOLEM missions have been discussed, and the subsystem weight breakdowns have been tabulated for the LEM, LEM/S and MOLEM.

This section will present the general arrangement of the preferred LEM/S and MOLEM concepts, a summary of subsystems requiring modifications and a summary of subsystem weights.

9.15.1 LEM SHELTER CONCEPTS

The LEM/S general arrangement is shown in Figure 9-31. This figure shows the location of all external equipment on the ascent stage, and all descent stage equipment. Also shown are the cg locations for each stage and the composite ascent/descent stage cg location.

The LEM/S internal arrangements has been previously discussed and is shown in Figures 9-1, and 9-2. Figure 9-1 is repeated here for convenience.

9.15.2 MOLEM CONCEPTS

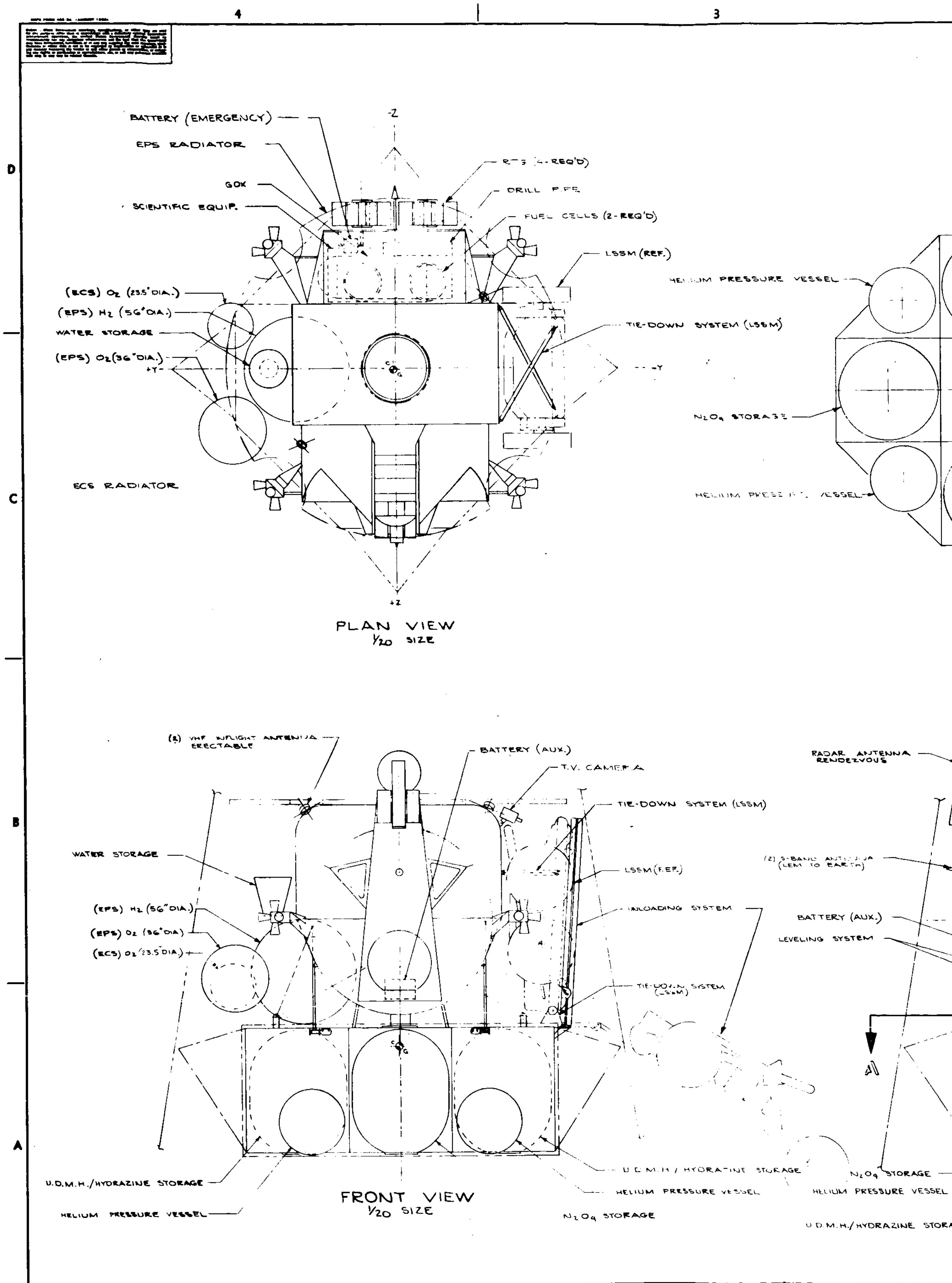
The MOLEM External Arrangement Concept is shown in Figure 9-32. Related drawings indicated in Figure 9-32 include an Internal Arrangement Concept, Unloading Concept, Wheel Unfolding Concept and a LEM external visibility diagram.

The center of gravity coordinates for the MOLEM are furnished for the folded and unfolded wheel positions. Also, cg values are given with and without the crew and crew accessories for the unfolded wheel position.

All of the external equipment items for MOLEM are shown in Figure 9-32.

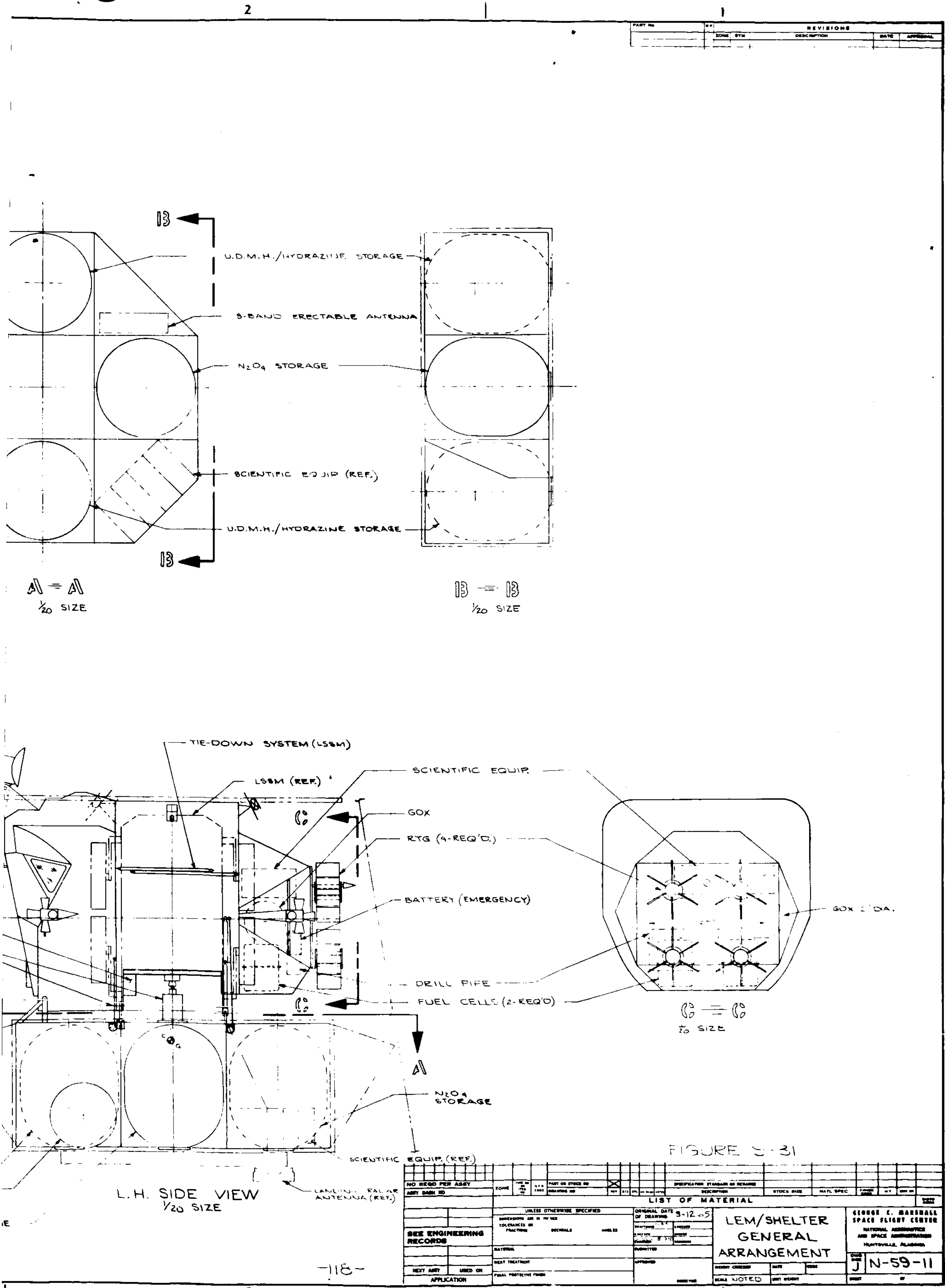
The internal arrangement drawing for MOLEM was discussed in Section 9.3.3 and is shown in Figure 9-4. For convenience, Figure 9-4 is repeated and included in this section.

BLANK PAGE 190



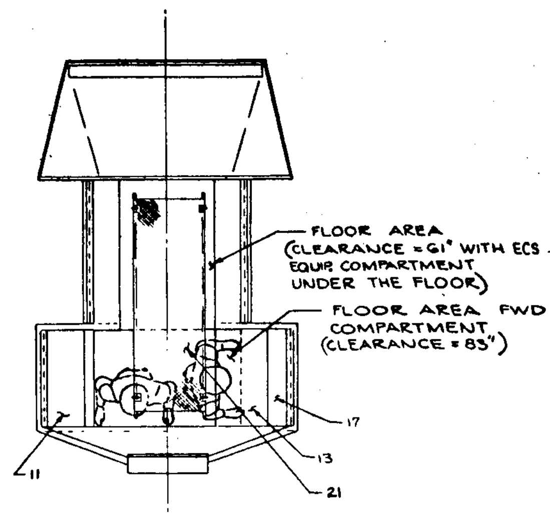
4
3
D
C
B
A
BATTERY (EMERGENCY)
EPS RADIATOR
GOX
SCIENTIFIC EQUIP.
DRILL
FUEL CELLS (2-REQ'D)
LSSM (REF.)
-Z
(ECS) O_2 (23.5" DIA.)
(EPS) H_2 (56" DIA.)
WATER STORAGE
(EPS) O_2 (36" DIA.)
+Y
TIE-DOWN SYSTEM (LSSM)
-Y
ECS RADIATOR
+Z
PLAN VIEW
1/20 SIZE
HELIUM PRESSURE VESSEL
N_2O_4 STORAGE
(2) VHF INFLIGHT ANTENNA ERECTABLE
BATTERY (AUX.)
T.V. CAMERA
TIE-DOWN SYSTEM (LSSM)
WATER STORAGE
LSSM (REF.)
(EPS) H_2 (56" DIA.)
(EPS) O_2 (36" DIA.)
(ECS) O_2 (23.5" DIA.)
UNLOADING SYSTEM
TIE-DOWN SYSTEM (LSSM)
U.D.M.H./HYDRAZINE STORAGE
HELIUM PRESSURE VESSEL
FRONT VIEW
1/20 SIZE
U.D.M.H./HYDRAZINE STORAGE
HELIUM PRESSURE VESSEL
N_2O_4 STORAGE
RADAR ANTENNA RENDEZVOUS
(2) S-BAND ANTENNA (LEM TO EARTH)
BATTERY (AUX.)
LEVELING SYSTEM
A
N_2O_4 STORAGE
HELIUM PRESSURE VESSEL
U.D.M.H./HYDRAZINE STORA

141

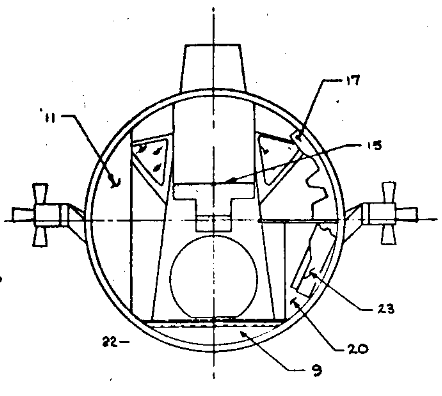


B
U.D.M.H./HYDRAZINE STORAGE
S-BAND ERECTABLE ANTENNA
N_2O_4 STORAGE
SCIENTIFIC EQUIP (REF.)
U.D.M.H./HYDRAZINE STORAGE
A — A
1/20 SIZE
B — B
1/20 SIZE
TIE-DOWN SYSTEM (LSSM)
LSSM (REF.)
SCIENTIFIC EQUIP.
GOX
RTG (4-REQ'D.)
BATTERY (EMERGENCY)
DRILL PIPE
FUEL CELLS (2-REQ'D)
GOX
C — C
1/20 SIZE
C
C_G
A
N_2O_4 STORAGE
SCIENTIFIC EQUIP. (REF.)
LANDING RADAR ANTENNA (REF.)
L.H. SIDE VIEW
1/20 SIZE
LIST OF MATERIAL
SEE ENGINEERING RECORDS
ORIGINAL DATE OF DRAWING 3-12-65
LEM/SHELTER
GENERAL
ARRANGEMENT
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA
J
N-59-11
SCALE NOTED
REVISIONS

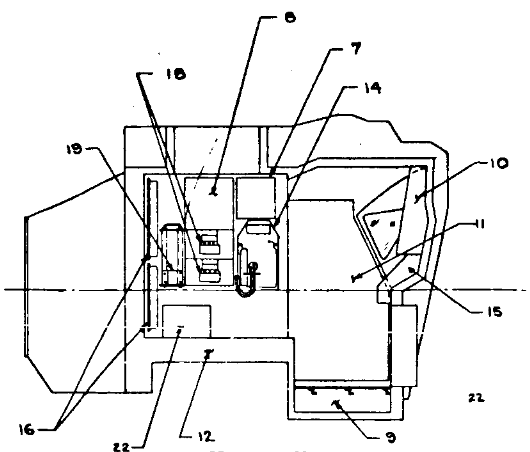
FIGURE 5-31


FLOOR AREA
(CLEARANCE = 61" WITH ECS
EQUIP. COMPARTMENT
UNDER THE FLOOR)
FLOOR AREA FWD
COMPARTMENT
(CLEARANCE = 83")
17
13
21
11

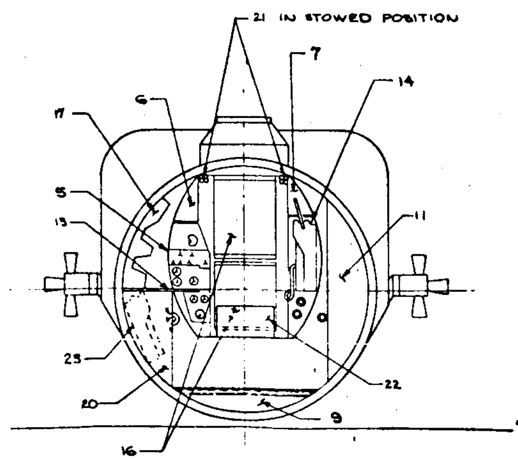
F — F


17
11
15
23
20
22
9

D — D

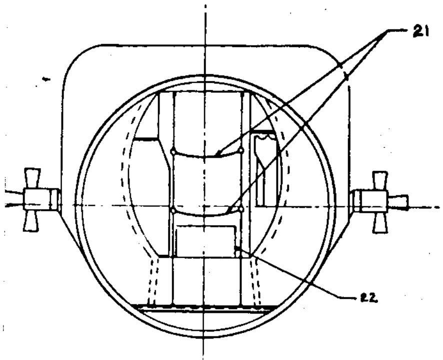

8
7
18
14
19
10
11
15
16
22
12
9
22

B — B

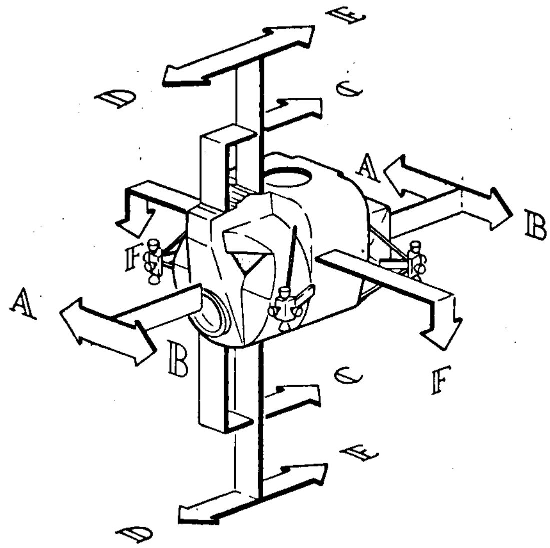

21 IN STOWED POSITION
7
14
6
17
5
13
11
25
20
22
9
16

C — C

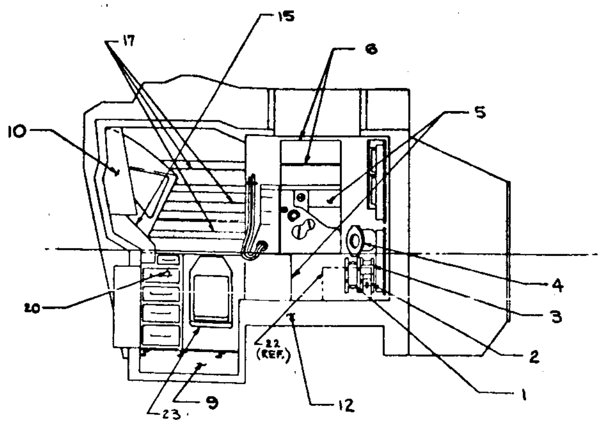
REVISIONS



E = E



NO SCALE



A = A

23 SPARE PLSS BACK PACK
22 SPARE SPACE SUIT CONTAINER
21 COLLAPSIBLE BUNKS
20 SCIENTIFIC EQUIP. STORAGE
19 PLSS BATTERY CHARGER
18 SPECIMEN CONTAINERS
17 CONTROLS & DISPLAYS
16 POWER SERVO ASSY & ELECTRONIC COUPLING DISPLAY UNIT (PSA & ECDU)
15 CONTROLS & DISPLAYS
14 PLSS
13 WORK TABLE
12 STORAGE CONTAINER EQUIPMENT
11 STORAGE AREA, LiOH (ECS)
10 STORAGE AREA, LiOH (PLSS) & FIRST AID
9 FOOD STORAGE
8 FOOD STORAGE
7 FOOD STORAGE
6 FOOD STORAGE
5 ECS EQUIP.
4 LIOH CARTRIDGE STORAGE
3 AUTOMATIC PUMP SWITCH
2 COOLANT RECIRCULATION ASSY
1 REGENERATIVE HEAT EXCHANGER

FIGURE 9-1 (Repeat)

LIST OF MATERIAL

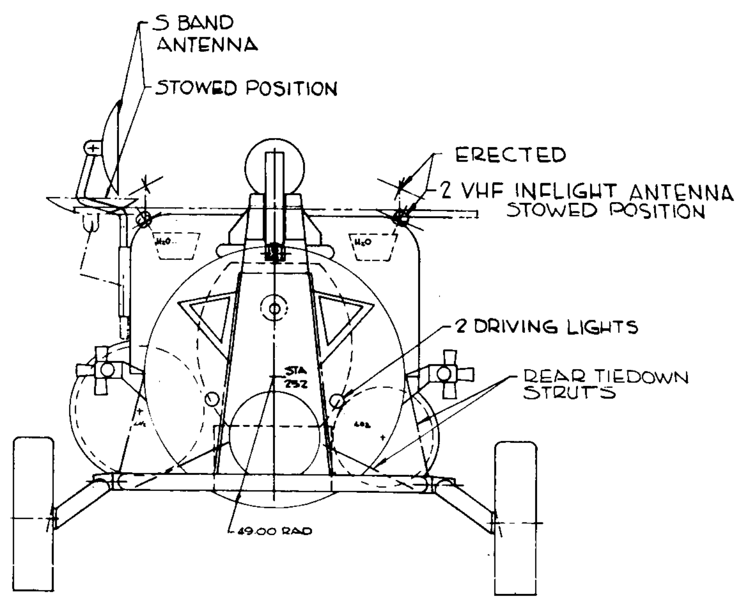
SEE ENGINEERING RECORDS

ORIGINAL DATE OF DRAWING 2-4-66

LEM SHELTER CONCEPT I INTERNAL ARRANGEMENT

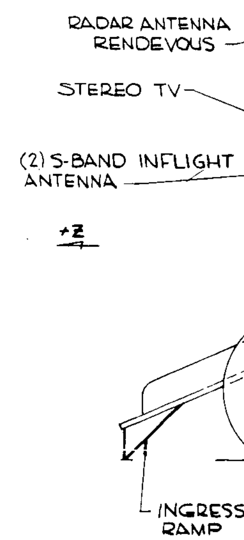
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-4



FRONT VIEW

MOLEM WEIGHT & CG SUMMARY				
	WEIGHT POUNDS	CG COORDINATES INCHES X	Y	Z
MOLEM (WHEELS UNFOLDED, NO UNLOADING EQUIP, NO CREW)				
MOLEM (WHEELS UNFOLDED NO UNLOADING EQUIP INCLUDES 279 LBS CREW ACCESSORIES AND 352 LBS. FOR THE CREW)				

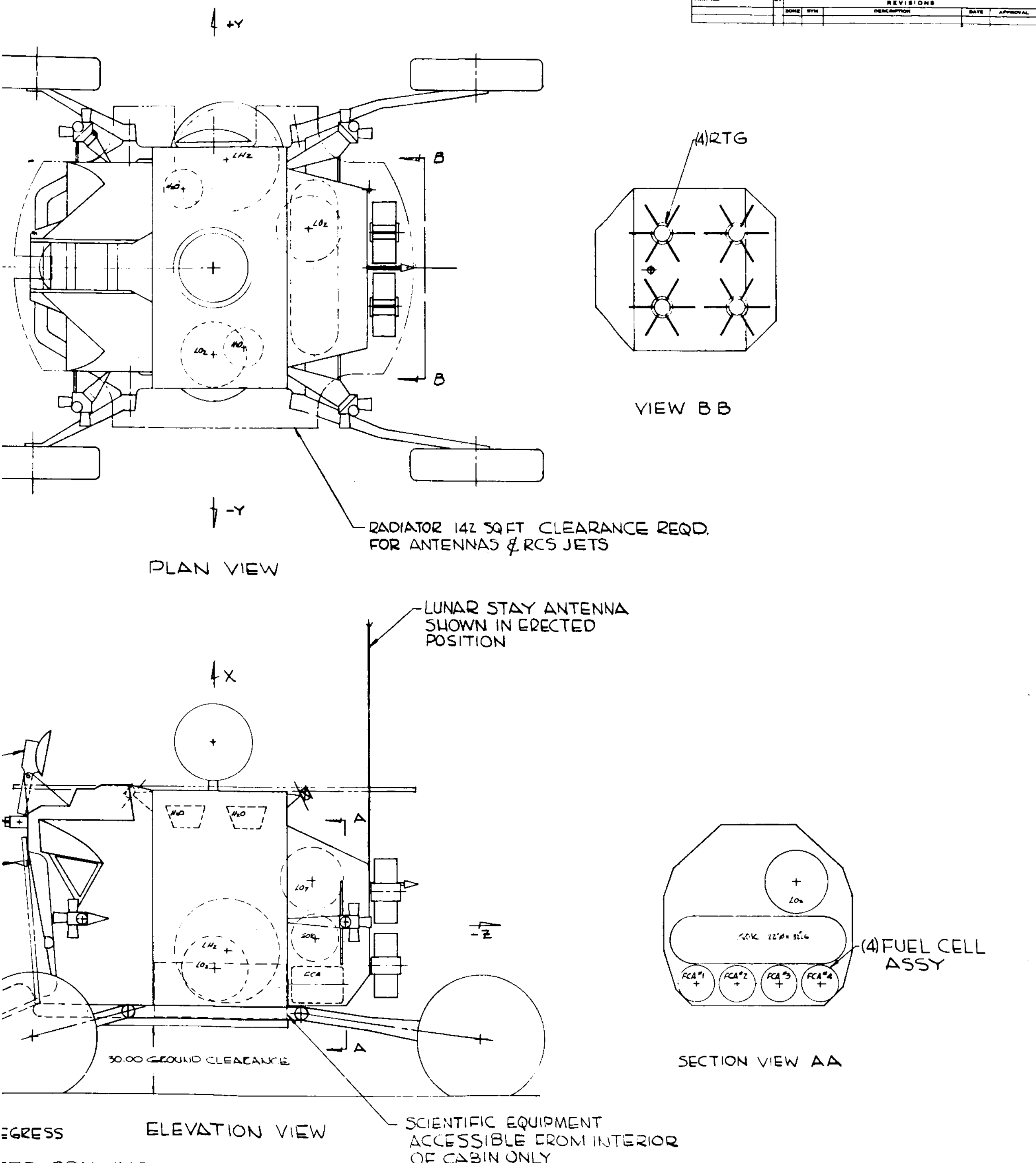


RELA
DWG

FIG No

N-5
N-5

N-5
SHT
N-5



ED DRAWINGS

Nº	DRAWING TITLE
9-7	VISIBILITY DIAGRAM MOLEM CONCEPT
9-9	UNLOADING & TIEDOWN SYSTEM MOLEM CONCEPT
9-10 1 & 2	WHEEL UNFOLDING & MOBILITY MOLEM CONCEPT
9-6	INTERNAL ARRANGEMENT MOLEM CONCEPT

FIGURE 9-32

LIST OF MATERIAL

SEE ENGINEERING RECORDS

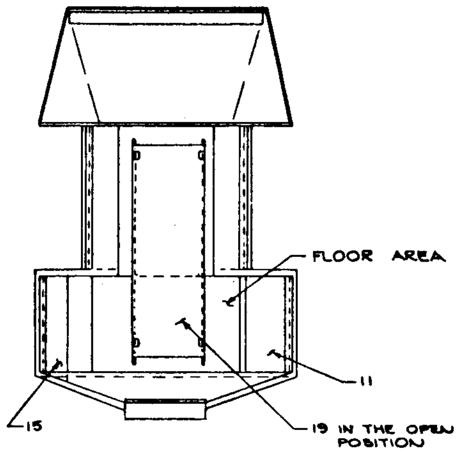
ORIGINAL DATE OF DRAWING 9 MAR 65

EXTERNAL ARRANGEMENT MOLEM CONCEPT

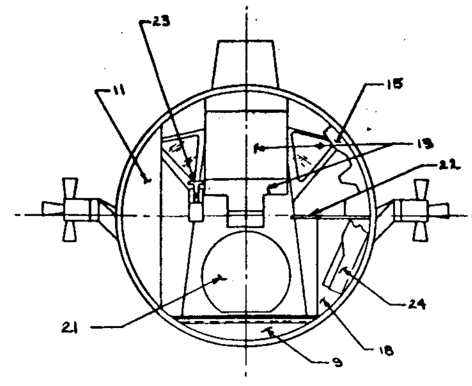
GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-12

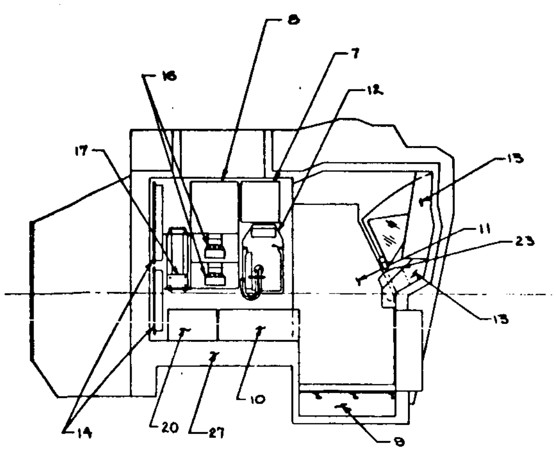
SCALE 1/20


FLOOR AREA
11
15
19 IN THE OPEN POSITION

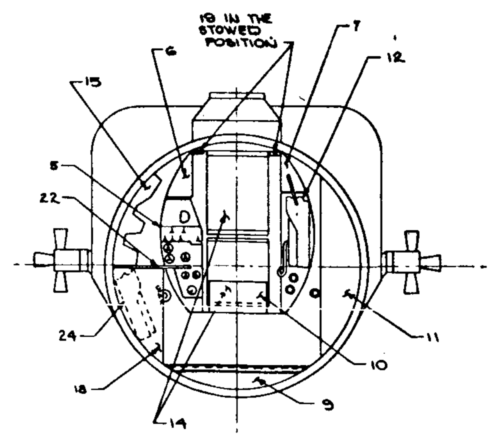
F — F


23
11
15
13
22
24
21
18
9

D — D


8
16
7
12
17
13
11
23
13
14
20
27
10
9

B — B

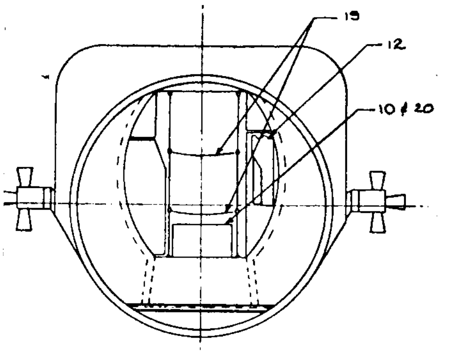

19 IN THE STOWED POSITION
7
6
15
12
5
22
24
18
14
10
11
9

C — C

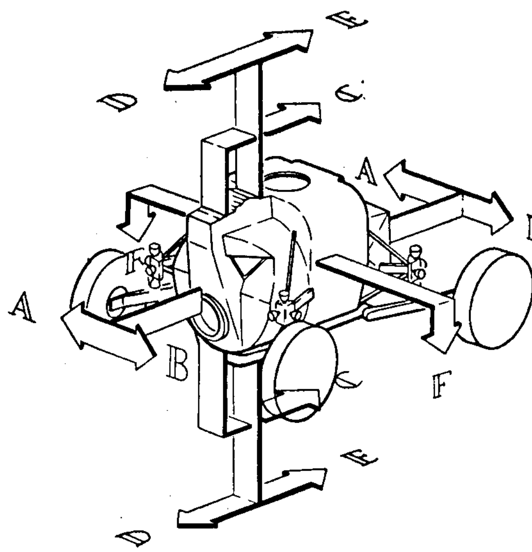
2 1

PART No.		ZONE	SYM	REVISIONS DESCRIPTION	DATE	APPROVAL

D

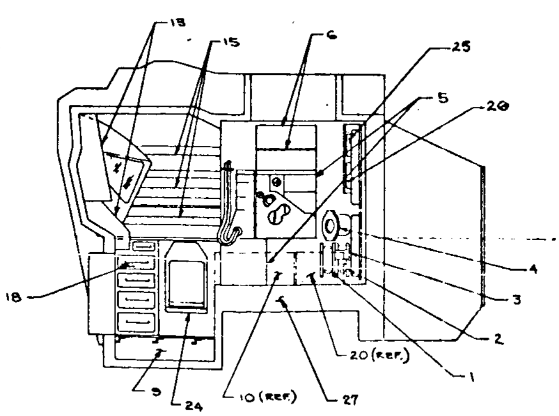


E — E



NO SCALE

C



A — A

B

27 STORAGE CONTAINER EQUIPMENT
26 RELAY BOX (ECS)
25 CABIN PRESSURE SWITCH (ECS)
24 SPARE PLSS BACK PACK
23 LOCOMOTION CONTROL LEVER
22 WORK TABLE
21 FORWARD HATCH
20 SPARE SPACE SUIT IN CONTAINER
19 COLLAPSIBLE BUNKS
18 SCIENTIFIC EQUIP. STORAGE
17 PLSS BATTERY CHARGER
16 SPECIMEN RETURN CONTAINERS
15 CONTROLS & DISPLAYS
14 POWER SERVO ASSY & ELECTRONIC COUPLING DISPLAY UNIT (PSA & ECDU)
13 CONTROLS & DISPLAYS-N&G, LOCOMOTION
12 PLSS
11 STORAGE AREA, LiOH (ECS) EMERGENCY EQUIP, PERSONAL HYGIENE, FOOD PREP. EQUIP. & MISC.
10 STORAGE AREA, LiOH (PLSS) & FIRST AID
9 FOOD STORAGE
8 FOOD STORAGE
7 FOOD STORAGE
6 FOOD STORAGE
5 ECS EQUIP.
4 LiOH CARTRIDGE STORAGE
3 AUTOMATIC PUMP SWITCH
2 COOLANT RECIRCULATION ASSY
1 REGENERATIVE HEAT EXCHANGER

A

FIGURE 9-4 (Repeat)

LIST OF MATERIAL

SEE ENGINEERING RECORDS

MOLEM
INTERNAL
ARRANGEMENT

GEORGE C. MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ALABAMA

J N-59-6

SCALE 1/20

2 1

9.15.3 WEIGHT COMPARISON

A comparison of subsystem weights for the LEM, LEM/S and MOLEM is given in Table 9-23. The weight comparison indicates the LEM/S and MOLEM total weights do not exceed the existing LEM weight.

A summary Table has been prepared tabulating weight and cg coordinate data for LEM, LEM/S and MOLEM. This information is listed in Table 9-24 for the ascent, descent and combined stages for the LEM, LEM/S and MOLEM.

The payload weight capability is shown in Table 9-25 for the LEM/S and MOLEM. This Table shows in the first column the total weights for LEM and for the LEM/S and, MOLEM concepts. The succeeding columns show the remaining weights after removing the tiedown, unloading and leveling equipment; the scientific instrumentation; and the LSSM. Finally the total payload capability for the LEM/S is shown as 3,636 pounds and for the MOLEM as 1,878 pounds. The payload capability is based upon the LEM weight as of November 1, 1964.

TABLE 9-23 WEIGHT SUMMARIES FOR LEM, LEM/S AND MOLEM*

WEIGHT SUMMARIES FOR LEM, LEM/S & MOLEM						
WEIGHT SUMMARIES FOR LEM, LEM/S & MOLEM	WEIGHT - POUNDS					
SUBSYSTEM	LEM		LEM/S		MOLEM	
	A/S	D/S	A/S	D/S	A/S	D/S
Structure	(1,061.3)	(1,118.3)	(1,146.1)	(1,118.3)	(1,446.1)	(1,118.3)
Stabilization & Control	(70.6)	(13.7)	(70.6)	(13.7)	(70.6)	(13.7)
Navigation & Guidance	(276.9)	(28.0)	(304.9)	(28.0)	(276.9)	(28.0)
Crew Provisions	(190.6)	(5.0)	(394.9)	(5.0)	(429.9)	(5.0)
Environmental Control	(308.5)	(236.5)	(742.8)		(661.8)	
Landing Gear		(410.0)		(410.0)		(410.0)
Instrumentation	(215.4)	(175.0)	(2,196.7)	(655.0)	(1034.7)	(175.0)
Operational	215.4	5.0	286.7	5.0	296.7	5.0
Scientific		170.0	1,910.0	650.0	738.0	170.0
Propulsion System	(5,236.3)	(17,529.8)		(17,529.8)		(17,529.8)
Propulsion Inert	610.6	1,443.8		1,443.8		1,443.8
Propellant (Includes 166# Trapped)	4,625.7	16,086.0		16,086.0		16,086.0
Electric Power Supply	(956.2)	(355.8)	(2,096.7)	(124.9)	2521.3	(124.9)
Reaction Control	(855.1)		(487.7)		(487.7)	
Propulsion Inert	368.6		362.6		362.6	
Propellant (Includes 28# Trapped)	486.5		125.1		125.1	
Communications	(117.7)	(27.3)	(110.2)	(38.8	(151.9)	(1.5)
Controls & Displays	(236.3)		(88.2)		(118.2)	
Mobility					(1026.0)	
Unloading Tiedown & Leveling Equipment	*	*	(227.0)		(500.0)	
* LEM tiedown equipment included in structure			**		**	
Totals	9,524.9	19,899.4	7865	19,923	8,725	19,406

**Weight total for the LEM/S & MOLEM does not include 10% contingency

TABLE 9-24a

LEM/S AND

MOLEM WEIGHT & C. G. SUMMARY

CONFIGURATION	WEIGHT (POUNDS)	C. G. COORDINATES*		
		x Inches	y Inches	z Inches
LEM/S Ascent Stage (Including LSSM)	8652	252.9	.03	1.4
LEM/S Descent Stage	19,923	159.2	-.8	-.8
LEM/S (Both Stages)	28,575	187.6	-.5	-.1
MOLEM (Wheels Folded, includes 500 lb. Unloading Equipment)	9548	247.6	1.6	1.2
Descent Stage (MOLEM Conversion)	19,406	159.4	-.3	-.4
MOLEM (Both Stages)	28,954	188.5	.3	.1
MOLEM (Wheels Unfolded, no Unloading Equipment, no Crew)	9048**	71.8***	1.7	-3.3
MOLEM (Wheels Unfolded, no Unloading Equipment, Includes 279 lbs. Crew Accessories and 352 lbs. for the Crew)	9679**	72.4***	1.6	.1

* Dimensions correspond to LEM Coordinate system.

** Weight totals include
- 10% Contingency on basic LEM/S weight 7612.0 pounds
- 10% Contingency on basic MOLEM weight of 8225.1 pounds + 500 pounds for unloading equipment.

*** Height above level lunar surface.

Note: This Table is repeated in a separate Confidential Appendix to this report. In addition, Confidential data has been added to the Table in the Appendix.

TABLE 9-24b

LEM/S AND
MOLEM WEIGHT & C. G. SUMMARY

CONFIGURATION	WEIGHT (POUNDS)	C. G. COORDINATES		
		x Inches	y Inches	z Inches
LEM Ascent Stage	9, 525	242.7	.3	.1
LEM Descent Stage	19, 899	159.7	.3	-1.5
LEM (Both Stages)	29, 424	186.6	.3	-1.0
LEM/S Ascent Stage (including LSSM)	8, 652 **	252.9	.03	1.4
LEM/S Descent Stage	19, 923.0	159.2	-.8	-.8
LEM/S (Both Stages)	28, 575.0	187.6	-.5	-.1
MOLEM (Wheels Folded, Includes 500 lbs. Unloading Equipment	9, 548 **	247.6	1.6	1.2
Descent Stage (MOLEM Conversion)	19, 406	159.4	-.3	-.4
MOLEM (Both Stages)	28, 954	188.5	.3	.1
MOLEM (Wheels Unfolded, no Unloading Equipment, no Crew)	9, 048	71.8 ***	1.7	-3.3
MOLEM (Wheels Unfolded, no Unloading Equipment, Includes 279 lbs. Crew Accessories and 352 lbs. for the Crew	9, 679	72.4 ***	1.6	.1

* Dimensions correspond to LEM Coordinate system.

** Weight totals include:
10% Contingency on Basic LEM/S weight of 7, 865.0 pounds.
10% Contingency on Basic MOLEM weight of 8, 225.1 pounds + unloading equipment weight of 500 lbs.

*** Height above level lunar surface.

TABLE 9-25 PAYLOAD WEIGHT CAPABILITY FOR LEM/S AND MOLEM*

PAYLOAD WEIGHT CAPABILITY FOR LEM/S AND MOLEM	WEIGHT - POUNDS					
	LEM		LEM/S		MOLEM	
ITEM	A/S	D/S	A/S	D/S	A/S	D/S
Total Weight	9,525	19,899	8,652	19,923	9,548	19,406
Less Weight of Tiedown, Unloading and Leveling Equipment			-227		-500	
Sub Total			8,425	19,923	9,048	19,406
Less Weight of Scientific Instrumentation			-710	-650	-738	-170
Sub Total			7,715	19,273	8,310	19,236
Less Weight of LSSM			-1,200			
Sub Total			6,515	19,273	8,310	19,236
*Total Payload Capability			3,010	626	1,215	663

* The weights shown in this column represent the payload weights which may be added to the LEM/S and MOLEM concepts without exceeding the LEM weight as shown in the LEM November 1, 1964 weight statement.

9.15.4 SIGNIFICANT MODIFICATIONS

A summary of modifications for the conversion of LEM to a LEM/S, or MOLEM has been compiled and is presented in Table 9-26. All of the subsystems have been included with the exception of the Stabilization and Control Subsystem and the Landing Gear Subsystem. Since no modification was necessary, these two subsystems were not included in Table 9-26.

All modifications summarized in Table 9-26 are based on data previously presented in this report for the various subsystems.

TABLE 9-26

SUMMARY OF MODIFICATIONS FOR LEM CONVERSION TO LEM/S OR MOLEM

	MODIFICATIONS	
SUBSYSTEM	LEM/S	MOLEM
STRUCTURE	Increased outer bumper sheet thickness to .030 inch and increased thermal insulation to 1 inch. Extensive fabrication rework required, however, considered to be minimum design modification.	
		Added chassis for mobility function. Major design modification.
N & GS	Added position plotter and command panel to existing LEM Subsystem.	
	Added beacon transmitter and antenna to LEM/S for LSSM Communications. Minimum Modification	Added odometer. Directional and vertical gyros obtained by modifying IMU. Minimum Modification
CREW PRO-VISIONS	Added sufficient food and LiOH for extended mission. Modified crew stations to provide sleeping space and work area. Minimum design modification.	
		Added driving control station
ECS	Increased supply of breathing O_2, water and LiOH. Modified heat transport primary and secondary coolant loops to include radiator. Modified water management section to cool and store fuel cell water (added condenser and changed tank configuration). Added cabin repressurization storage container system. Minimum modification.	
INSTRU-MENTATION	Added sensors to all subsystems for additional checkout and monitoring. Minimum modification.	
	Added LSSM, deep drill, ESS and other scientific equipment to existing LEM allocation. Minimum modification.	Added deep and shallow drills, ESS and other scientific equipment to LEM allocation. Minimum modification.
PROPULSION	Removed entire ascent propulsion subsystem including engine, propellant, tankage, plumbing and engine controls. Minimum modification.	

TABLE 9-26 (Continued)

SUMMARY OF MODIFICATIONS FOR LEM

CONVERSION TO LEM/S OR MOLEM

<table>
<tr><th></th><th colspan="2">MODIFICATIONS</th></tr>
<tr><th>SUBSYSTEM</th><th>LEM/S</th><th>MOLEM</th></tr>
<tr><td rowspan="2">EPS</td><td colspan="2">Increased supply of cryogenic reactants, added 4 RTG units for dormant power use, and added batteries for auxiliary power. Minimum modification.</td></tr>
<tr><td>Changed primary power supply from three .9 kw open cycle fuel cell modules, to two 1.56 kw closed cycle fuel cell modules incorporating a radiator. Minimum modification.</td><td>Changed primary power supply from three .9 kw open cycle fuel cell modules modules to four 2 kw closed cycle fuel cell modules incorporating a radiator. Minimum modification.</td></tr>
<tr><td>RCS</td><td colspan="2">Removed propellant associated with ascent, rendezvous and docking maneuvers. Minimum modification.</td></tr>
<tr><td rowspan="2">COMMUNI-
CATIONS</td><td colspan="2">Removed steerable S-band antenna. Added two command detector and decoders. Minimum modification.</td></tr>
<tr><td>Added one TV camera.</td><td>Added a Stereo Television camera. Transferred S-band erectable antenna with R.F. cables and VHF lunar stay antenna with R.F. cables to ascent stage. Minimum modification.</td></tr>
<tr><td rowspan="2">CONTROLS &
DISPLAYS</td><td colspan="2">Removed all controls and displays associated with manned flight phase of mission, and all duplicate controls and displays not considered necessary. Remaining controls and displays relocated in System's Engineer console and on forward crew compartment bulkhead. Considerable rewiring will be required, however, this is a minor design modification.</td></tr>
<tr><td></td><td>Added mobility and N & GS Controls and displays in area previously occupied by flight controls and displays.</td></tr>
<tr><td>TIEDOWN
UNLOADING
& LEVELING</td><td>Added equipment for unloading LSSM, and equipment for leveling shelter. Modified existing tiedown structure attach fittings. Minimum modification.</td><td>Added equipment for unloading. Used existing tiedown structure attach fittings. Minimum modification.</td></tr>
</table>

TABLE 9-26 (Continued)

SUMMARY OF MODIFICATIONS FOR LEM CONVERSION TO LEM/S OR MOLEM

	MODIFICATIONS	
SUBSYSTEM	LEM/S	MOLEM
MOBILITY	LSSM supplemental payload added to provide mobility aid for LEM/S Crew. Minor modification.	Added mobility system consisting of wheels, drive motors, transmission, steering motors, suspension system, brakes, etc. Major modification.

SECTION 10.0

CONCLUSIONS

From the information presented in the preceding sections of this report the following conclusions can be made:

- Sufficient volume is available within the confines of the existing LEM payload to store an adequate supply of life support, electric power, and environmental control expendables to meet the needs of the LEM/S and MOLEM missions.

- The weight increase attributed to the addition of equipment and expendables necessary for the LEM/S and MOLEM missions, is offset by the deletion of LEM equipment serving no useful function for either the LEM/S or MOLEM mission. The net result is a decrease in total weight for the LEM/S and MOLEM configurations when compared to the existing LEM.

- Adequate volume within the payload envelope is available to permit the use of the LEM/S and LSSM, or MOLEM, for the AES mission.

- To accomplish the LEM/S and/or MOLEM mission the LEM Ascent Propulsion Subsystem should be removed. This can be done without invalidating the minimum modification concept.

- The existing LEM open cycle fuel cells and the ECS heat transport subsystem are in no way adequate for use with the LEM/S or MOLEM mission, without incurring an extreme weight penalty.

- The supercritical cryogenic storage system used on LEM is not adequate for the LEM/S & MOLEM mission. A subcritical cryogenic storage system is required because of the increased mission duration. Additional cryogenics are needed for the longer duration mission and the 6 month storage period.

- The limited free floor space available in the LEM/S and MOLEM is considered to represent a major problem area. The efficiency of the two man crew when confined to such a small area for 14 days will, in all probability, be drastically reduced.

- The recommended LEM/S and MOLEM subsystem concepts do not violate the minimum modification criteria (excepting for the MOLEM mobility subsystem). This conclusion is based upon a study of each individual subsystem with some attention to the interrelated effects of one subsystem upon another. However, the time allocated to this task precluded serious study of the integrated LEM/S and MOLEM systems. Succeeding overall system studies may establish the conversion of LEM to a LEM/S is in fact a major modification.

- The MOLEM modification is not considered feasible within the framework of the minimum modification concept. Considerable analyses are required to substantiate the structural integrity of the MOLEM system for the dynamic loads to be encountered while traversing the lunar surface. In all likelihood the analyses will indicate considerable redesign of primary structure is required. Further, an entirely new proof test program will be required.

- An airlock cannot be incorporated in the LEM/S or MOLEM without violating the minimum modification requirements. The lack of an airlock jeopardizes the mission and places severe reliability and habitability requirements on the suit system.

- An oxygen storage container concept shows promise for conserving cabin oxygen during ingress/egress operations and is recommended for use with the LEM/S and MOLEM.

- The LEM/S and MOLEM payload capabilities were determined to be 3,636 pounds and 1,878 pounds respectively. This capability is based upon not allowing the LEM/S and MOLEM weights to exceed the total LEM weights as of November 1, 1964. This capability may be allocated for scientific instrumentation, mobility aids, leveling equipment and unloading equipment.

SECTION 11.0

RECOMMENDATIONS

The information presented in this report represents a cursory investigation of the applicability of the various LEM subsystems to the LEM/S and/or MOLEM mission requirements. This report indicates the problem areas involved in the change-over from two day vehicle, to a fourteen day vehicle, with the additional requirement of a six month dormant period on the lunar surface. Further study is required to establish the optimum subsystem design. Suggested areas for further investigation include:

- Establishing the effects of restricted free floor space on crew efficiency. This information may be available from previous tests. If not, it would appear to be advantageous to conduct tests in which two subjects are required to participate in activities which simulate the actual LEM/S and/or MOLEM mission.

- The radiators used for the ECS and EPS heat transport section. The radiators may be integrated into a single unit, and this change along with the effective integration of the storage container concept requires further study of the ECS for the LEM/S & MOLEM.

- The incorporation of an airlock into the LEM configuration considering the minimum modification concept. An up-to-date assessment of materials for use with a collapsible airlock is required.

- The lifetime of LEM equipment. This should be determined, and where necessary determine the possibility of extending this lifetime.

- Optimization of the Electrical Power Subsystem. The effective utilization of the fuel cells and nuclear power assemblies to supply the primary power requirements must be established before an optimum EPS concept may be realized.

- The N&GS method used for the unmanned lunar landing. Further studies are required to determine whether obstacle avoidance equipment should be developed or whether homing devices such as beacons may be used. Assistance from a previous landed astronaut is another possible way of accomplishing the unmanned lunar landing.

- Certain vital monitoring functions, requiring the intermittent operation of electronic equipment are necessary during the six month dormant period. First of all, additional investigation of the electronic equipment power requirements is essential to minimize the demands on the thermal control systems. Secondly, passive thermal control systems should be studied for use during the dormant period.

- Additional study effort, with respect to unloading of the LSSM from the descent stage to the lunar surface, is considered to be warranted to further demonstrate the feasibility of the proposed system, and to develop greater unloading capability.

- The restrictions imposed on scientific experimentation due to the omission of a vacuum workshop should be determined. Also, the possibility of including a vacuum workshop should be studied.

SECTION 12.0

REFERENCES

1. LEM Vehicle Application As a Shelter or Mobile Laboratory, NASA, MSFC, R-P&VE-AB, Memorandum R-P&VE-AB-101, November 1964, C. R. Darwin.

2. Lunar Excursion Module Familiarization Manual LMA 790-1, Grumman Aircraft Engineering Corporation, NAS9-1100 Exhibit E, paragraph 10.2, July 1964.

3. NASA Inspection and Review of Lunar Excursion Module, M-5 Mockup, LMU-250-3, Grumman Aircraft Engineering Corporation, Bethpage, New York, October 1964.

4. LEM Application to Lunar Shelters and Mobile Vehicles, Task Order N-59, Contract NAS8-11096, NASA, MSFC, December 4, 1964.

5. Task Report on Mission Operational Aspects Study, ALSS MOLAB Studies, NASA Technical Memorandum, NASA TM X-53032.2, R. L. King and O. R. Myers, March 1964.

6. Miscellaneous Guidelines and Criteria for use in ALSS Studies, R-P&VE-AB-64-55, NASA, MSFC, Memorandum From J. C. Rains, R-P&VE-AB to Schaefer, R-AERO-SP, July 20, 1964.

7. Engineering Lunar Model Surface (ELMS), KSC-TR-83-D, R. L. Mason, W. M. McCombs and D. C. Cramblit, September 4, 1964.

8. Conceptual Design of Local Scientific Survey Module Systems, R. L. King & S. O. Bresin, NSL E30-6, Contract NAS8-11096, Northrop Space Laboratories, April 1964.

9. Task Report on Viewing Port Study, ALSS MOLAB Studies, NASA ALSS Bulletin 001, G. J. Youngblood, August 1964.

10. Task Report on MOLAB Conceptual Design, G. Smith & D. Ross, NASA TMX-53032.3, ALSS MOLAB Studies, NASA Technical Memorandum, March 1964.

11. Lunar Surface Vehicle Studies, Presentation by Northrop Space Laboratories, Hawthorne, California, Brochure dated October, 1964.

12. Apollo Experiments Support Studies, Environmental Control System Study, Task Order N-13, Contract NAS8-11096, NSL E30-30, Otto R. Kosfeld, December 1964.

13. Lunar Surface Primary Meteoroid Flux and Puncture Model for Lunar Mobile Laboratory (LMOL) Studies, Vaughan, O. & Dalton, C,NASA MSFC, Aero-Astrophysics Office (R-Aero-Y) Memorandum R-Aero-Y-26-64, April 22, 1964.

14. Annex "D" Radiation Shielding, NASA MSFC, R-Aero-S, April 27, 1964.

15. Design and Analyses of Unloading and Tiedown Systems, Task Order N-39, Contract NAS8-11096, NASA, MSFC, by J. E. Ligocki and G. J. Youngblood, December 1964.

16. Lunar Mobile Laboratory Mission Operational Plan, Preliminary Report, NSL 930/63-1, Northrop Space Laboratories, December 2, 1963.

17. Electric Drives for Off-Highway Vehicles, H. J. McLean and H. Vitt, SAE Transactions, Volume 68, 1960.

18. Task Report on Mobility Systems Analysis, Task Order N-17, ALSS Bulletin 004, ALSS MOLAB Studies, E. R. Miles and T. Andrisan.

19. Mobility on the Lunar Surface, MTP-M-63-1, LLS Volume IX, NASA, Research Projects Division, March 15, 1963.

TECHNICAL APPENDIX

APPENDIX A

HUMAN FACTORS CONSIDERATIONS FOR LUNAR MISSIONS

The following capabilities are required of a shelter system designed to support two men on the lunar surface for two weeks:

1. Room for suit and backpack doffing and donning. If the suit and/or backpack must be donned without assistance it is probable that certain simple mechanical aids will be advisable or required. Wear of a suit for periods in excess of 6-8 hours is likely to result in the appearance of abrasions and blisters due to chafing of the skin. Additionally, wetting of skin by unevaporated perspiration and the collection of residue from dried perspiration may result in the appearance of other dermatological problems.

2. Room for various astronaut activities. Sleeping space for either astronaut and for both simultaneously, space for performance of personal tasks, for standby to leave shelter or while fellow crewman egresses or ingresses, for repressurization of shelter or airlock with both crewmen inside shelter.

3. Facilities for monitoring, control and required maintenance of the power system, mobility system, navigation system, environmental control system (discussed separately below; see No. 6), communication system, and data system.

4. Facilities for reprovisioning, maintaining, and storing backpacks (see Table A-1) and for storing tools, replacement parts and associated expendables.

5. Facilities for maintenance of pressure suits including drying of the suit, and for suit storage (see Table A-1).

6. Capability for control of environmental parameters:

   a. Maintenance of atmospheric pressure at 5 psia by release of gaseous oxygen.

b. Circulation of cabin atmosphere to cool occupants under shirtsleeve conditions.

c. Power supply to, and heat acceptance from the fluid cooled undergarment and its system heat exchanger.

d. Provision for up to 12 cubic feet per minute flow of cool, dry atmospheric gas through either suit for cooling of suited crewmen or drying of unoccupied suits. A flow of 4 cfm may be optimum during fluid cooling (see "c" above).

e. Removal of carbon dioxide gas as required to limit partial pressure in the cabin to below 8 mm Hg (millimeters of mercury).

f. Removal of organic gases in trace concentrations from metabolism of crewman, heating of electrical components, and laboratory procedures.

g. Heat rejection from the shelter system, temperature control at $70 \pm 5^{\circ}$ Fahrenheit, dehumidification of atmospheric gas to 50% relative humidity.

7. A supply of constant wear garments or facilities for laundering, and drying these garments.

8. Facilities for supplying 2 to 2.6 lbs/man day of gaseous oxygen exclusive of atmosphere vented or leaked to lunar vacuum.

9. Facilities for storage, preparation and consumption of food, and for storage of water.

10. Facilities for disposal or reuse of water recondensed from atmospheric vapor by the shelter ECS.

11. Facilities for waste disposal and/or neutralization. Waste will include food debris, feces, urine, cabin debris, wash water, expended CO_2 absorbent, etc.

As previously discussed, it is important that a lunar shelter be designed for "shirtsleeve" wear, requiring temporary storage of all components of the extra-vehicular suit system. Also, redundancy in the suit system is recommended. Weights and volumes of components of the suit system required for use in the LEM shelter, stationary or mobile, are given in Table A-1.

Table A-2 lists one man's energy requirements for varying daily schedules which include up to 6 hours of suit wear on the lunar surface. The water requirements shown in Table A-2 are the physiological requirements and practically all of this water is recoverable for ECS cooling.

Table A-3 lists weights of all life support expendables required for variations in schedule of 0 to 6 hours on the lunar surface. The point should again be made that water which is consumed by the crewmen is not necessarily lost to the system. In fact if urine were recycled and a lithium hydroxide system (which releases water) used to absorb carbon dioxide, a water surplus would accrue. High requirements for water are generated, however, with extensive space suit wear. Figure A-1 graphically presents expendable usage relationships for the variations in daily schedule previously considered. The use of water to cool the shelter has not been considered in this section.

It appears that considerable water may have to be provided for a LEM shelter mission for the following reasons:

- Power requirements for the shelter are relatively low, therefore less fuel cell water is generated.
- The ECS radiator provided may not be designed to radiate all environmental heat under the worst thermal conditions with both crewmen aboard.
- An open mobile vehicle may be provided, such as the LSSM, which does not manufacture water during operation, and which requires the crewman to utilize his suit system for cooling during extended stay-time on the lunar surface.

The probability arises that it will become advisable to plan the lunar mission to avoid conditions of lunar noon. Trade-offs which consider the value of extra-vehicular suit time against cost of such time need to be made. Under the conditions assumed in the included tables, about 2.75 hours of suit wear doubles the daily requirement for life support expendables. On first consideration it would seem advisable to emphasize extra-vehicular exploration during conditions which require evaporative cooling in the shelter so long as both crewmen are in the shelter. However the rate of water usage is so much higher during task activity on the lunar surface that even under these conditions it costs 3.9 times the weight in expendables to support the man outside the shelter.

For the two week LEM/S the aft area might be utilized as a sitting and sleeping space. Adequate comfort and support for sleeping would be provided by a chair which reclines to assume a configuration similar to the Mercury couch. The back may be inclined at any angle up to about 45° with support provided for the head including helmet.

Shielding of viewing ports should be possible in either the LEM/S or the MOLEM in order to reduce inward leakage of heat and to make it possible to darken the interior. The driver of the MOLEM should be positioned near his viewing port(s) so that his field of view is maximized for the size of the port.

Due to the small free volume provided it may prove advantageous to have one or both men stand while engaged in tasks inside the shelter. A standing position is considered optimum for a crewman engaged in the task of driving the MOLEM. Restraint in this position should be available. However to the extent practicable, the driving controls should also be usable as hand holds.

During wear of the pressurized suit it is very difficult for the individual to retain capability while seated unless he is restrained in the seated position. Such restraint must be of a type which holds his suit deformed into the "jacknifed" sitting position. Once conventional restraint is loosened with the suit pressurized it can be refastened only with difficulty. For these reasons a standing position is to be preferred for all tasks to be conducted with the suit pressurized. With these considerations in mind it is of some importance that the designer realize that standing will not be strenuous under conditions of lunar gravity. In fact, if restraint were provided for the head and body it would seem that the standing position might be relatively comfortable even for sleeping.

If both crewmen were in the crew compartment and not in their space suits it would be extremely difficult, in case of an emergency, for both of them to don their suits at the same time in the limited cabin volume. It is therefore recommended that one man remain suited at all times. The critical free volume condition for the LEM/S and MOLEM occurs when the crewmen are standing in the cabin in full extra-vehicular garb and the vehicle is depressurized.

An airlock allows one man to leave the vehicle while the second man remains under pressurization. The absence of an airlock jeopardizes the mission and places severe reliability and habitability requirements on the suit systems. Additionally, it affects the requirement for pressure vessel integrity under various conditions, especially that of strike by meteoroids.

A collapsible airlock which could be employed using the LEM hatch as the inner airlock door would relieve this critical design deficiency. An alternate solution would be to provide a collapsible, pressurizable partition between the forward and aft sections of the LEM cabin. Even if such a partition was not usable for routine depressurizations its effect upon mission safety could be considerable.

TABLE A-1

APOLLO SUIT AND PORTABLE LIFE SUPPORT SYSTEM (PLSS) VOLUMES & WEIGHTS

COMPONENT	Storage Dimensions (Ft)	Storage Volume (Cu. Ft.)	Weights (Lb)
Pressure garment with boots	1.0 x 1.5 x 1.5	2.25	
Helmet with communications	1.0 x 1.0 x 1.0	1.0	
Constant wear garment	1.0 x 1.0 x .5	.5	
Liquid cooled garment	1.0 x 1.0 x .5	.5	
Thermal protective garment	1.0 x 1.0 x .5	.5	50
Meteoroid protective garment	1.0 x 1.0 x 1.0	1.0	15
Emergency oxygen system	1.0 x 1.0 x .25	.25	3
Portable Life Support System (PLSS) with battery, but without LiOH cartridge, water, or oxygen (Expendables are 12-13 lbs additional)	2.1 x 1.0 x 1.25	2.62	35
Apollo Extra-Vehicular garb with PLSS:		8.62	103
Totals for 2 Systems		17.24	206
Emergency equipment:			
Torso assembly	1.0 x 1.5 x 1.5	2.25	22.0
Helmet with communications	1.0 x 1.0 x 1.0	1.0	8.5
Liquid cooled garment	1.0 x 1.0 x .5	.5	3.5
PLSS Battery	.33 x .33 x .33	.04	3.5
Suit Maintenance Gear	.5 x .5 x .5	.13	5.5
PLSS (complete uncharged)	2.1 x 1.0 x 1.25	2.62	36.0
	Total	6.54	79.0
Total Apollo Suits and Accessories		23.8	285

TABLE A-2

METABOLIC OUTPUT/DRINKING WATER RELATIONSHIPS WITH VARYING EXTRA-VEHICULAR SUIT WEAR; 1 MAN 24 HRS.

	Energy Expended - BTU/Day and Water Requirements - Lbs/Day						
Hr/Day Suit Wear on Lunar Surface	6	5	4	3	2	1	0
Energy Expended (BTU/Day):							
Doing Surface Tasks	9,000	7,500	6,000	4,500	3,000	1,500	0000
Doing Shelter Tasks	4,500	4,950	5,400	5,850	6,300	6,750	7,200
Sleeping (8 Hrs/Day)	2,400	2,400	2,400	2,400	2,400	2,400	2,400
Total Energy Output Per Day (BTU)	15,900	14,850	13,800	12,750	11,700	10,650	9,600
Water Requirements (Lb/Day):							
Urine and Feces	4.00	3.76	3.52	3.28	3.03	2.79	2.55
Respiration and Perspiration:							
Surface Tasks	4.50	3.75	3.00	2.25	1.50	.75	.00
Shelter Tasks	1.80	1.98	2.16	2.34	2.52	2.70	2.88
Sleep	.80	.80	.80	.80	.80	.80	.80
Total Water Output (Lbs/Day)	11.1	10.29	9.48	8.67	7.85	7.04	6.23
Water Formed During Metabolism	1.3	1.22	1.13	1.04	.95	.86	.78
Water Required for Drinking (Lb/Day)	9.8	9.07	8.35	7.63	6.90	6.18	5.45

Note: The total water requirement show above is based on the physiological requirements of one man for 24 hours. Practically all of this water is recoverable for use in ECS cooling or for reuse by purification in more sophisticated life support systems.

TABLE A-3
LIFE SUPPORT EXPENDABLES USAGE WITH VARIATIONS IN TASK ASSIGNMENT; ONE MAN, 24 HRS

	Energy Expended-BTU/Day and Expendable Requirements-Lbs/Day						
Time on Lunar Surface (Hr) Time in Lunar Shelter (Hr)	6 18	5 19	4 20	3 21	2 22	1 23	0 24
Energy Expended (BTU/Day)	15,900	14,850	13,800	12,750	11,700	10,650	9,600
Water Lost							
From Suit (Evaporated):	11.00	9.17	7.33	5.50	3.67	1.83	-0-
From Urine and Feces:	4.00	3.76	3.52	3.28	3.03	2.79	2.55
Miscellaneous Water Unretrieved:	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total Water Loss(Lb/Day)	16.00	13.93	11.85	9.78	7.70	5.62	3.55
Water Formed							
from Metabolism:	1.3	1.22	1.13	1.04	.95	.86	.78
from LiOH Use:	1.2	1.12	1.04	.96	.88	.80	.72
Total Water Gain (Lb/Day)	2.5	2.34	2.17	2.00	1.83	1.66	1.50
Net Water Required (Lb/Day)	13.5	11.59	9.68	7.78	5.87	3.96	2.05
Oxygen required	2.60	2.43	2.26	2.09	1.91	1.74	1.57
Food required	2.60	2.43	2.26	2.09	1.92	1.74	1.57
Activated Charcoal; Shelter	.27	.28	.29	.30	.32	.34	.36
LiOH required; 90% effic.	3.48	3.25	3.02	2.79	2.56	2.33	2.09
Activated Charcoal and Structure for the suit LiOH Cartridge	1.92	1.60	1.28	.96	.64	.32	0.0
Expendables, other than water (Lb/Day)	10.87	9.99	9.11	8.23	7.35	6.47	5.59
Total Expendables (Lb/Day)	24.37	21.58	18.79	16.01	13.22	10.43	7.64

Note: The expendable requirements shown above reflect the actual daily requirements of the mission, exclusive of water needed for ECS cooling. Drinking water requirements are not shown in this Table since drinking water may be recycled for cooling use. The mission water requirements are satisfied by water carried from Earth plus water produced by the fuel cells.

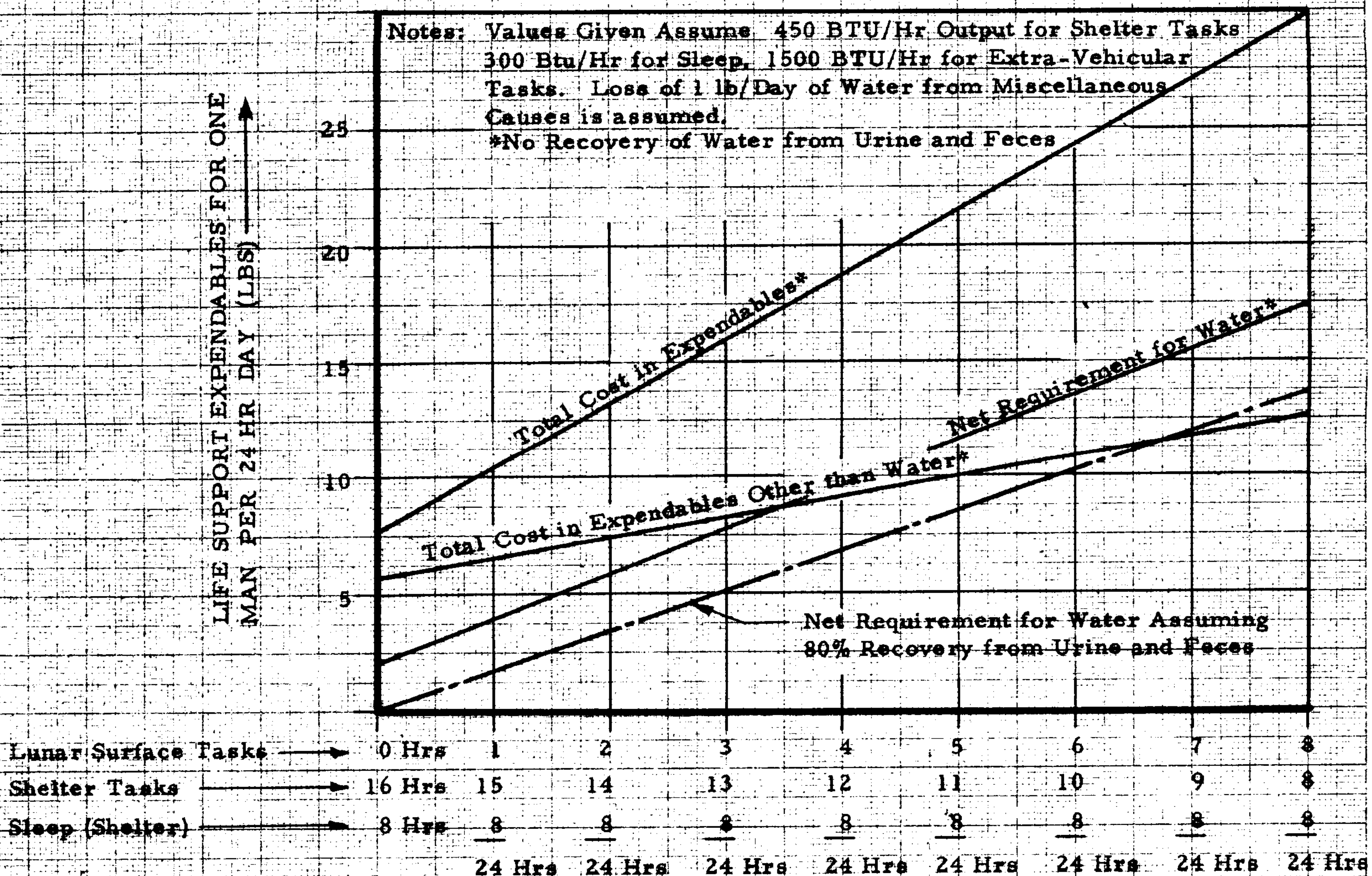


FIGURE A-1

LIFE SUPPORT EXPENDABLES USAGE WITH VARIATIONS IN TASK ASSIGNMENT

APPENDIX B

C. G. ANALYSES

The analyses for establishing the center of gravity for the LEM/S & MOLEM are included in this appendix. The weights & c.g.s for the LEM/A and LEM/D stages are shown in Table 9-24. These values were used for subsequent calculations. Additions and deletions were made for the ascent and descent stages to accomplish the LEM/S and MOLEM conversions. The changes required for the LEM/S and MOLEM are tabulated the accompanying tables.

B.1 LEM/S CENTER OF GRAVITY DATA

The items added to the LEM ascent stage and descent stage to accomplish the LEM/S conversion are shown in Table B-1 and B-2. These tables indicate the component weights and c.g. locations. Tables B-3 and B-4 indicate the weight and c.g. location of components removed from the LEM ascent stage and descent stage respectively.

The data contained in Tables B-1, B-2, B-3 and B-4 were used to determine the center of gravity shift associated with the conversion of LEM to a LEM/S. The resulting c.g. shift is indicated in Table 9-24.

B.2 MOLEM CENTER OF GRAVITY DATA

The Tables included in this section tabulate the subsystem component name, weight, and c.g. coordinates. Tables B-3 and B-5 show this information for the MOLEM ascent stage conversion and Tables B-4 and B-6 for the MOLEM descent stage conversion. This tabular data, along with the LEM weight and c.g. coordinates shown in Table 9-24 was used to compute the MOLEM weights and c.g. coordinates also listed in Table 9-24.

TABLE B-1

COMPONENTS ADDED TO LEM ASCENT STAGE FOR CONVERSION TO LEM/S

COMPONENT	WEIGHT	* C. G. LOCATION X (INCHES)	Y (INCHES)	Z (INCHES)
STRUCTURE	(84.8)			
Skin (Bulkhead)	33.1	250	0	70
Skin (Forward Crew Compartment)	22.7	250	0	50
Skin (Mid Section)	29.0	250	0	0
CREW PROVISIONS	(281.3)			
Space Suits	36.0	240	0	-12
Portable Life Support System	52.5	236	37	40
Radiation Dosimeter	2.0	240	0	-12
Suit mounted commun.	1.0	240	0	-12
Bio-Instrumentation	3.0	240	0	-12
Hammocks	10.0	298	0	0
Food	19.7	286	20	2.5
Food	20.8	284	-20	-3.0
Food	45.2	209	0	46
LiOH (PLSS)	46.1	284	0	74
Emergency Equip.	3.0	252	-37	38
Personal Hygiene	5.0	252	-37	38
Food Preparation Equip.	5.0	252	-37	38
Medical Equipment	5.0	267	0	72
Miscellaneous	17.0	252	-37	38
ENVIRONMENTAL CONTROL	(512.0)			
LiOH	69.6	284	0	74
Water & Tank	257.4	247	66	0
Radiator	110.0	315	0	20
Storage Container Assy.	75.0	252	0	0
INSTRUMENTATION	(1981.3)			
Instruments & Sensors	71.3	239	0	0
Scientific Equipment	1910.0			
LSSM	1200.0	268	-74	12
Drill Pipe	150.0	235	-16	-62
Misc. Drill Equip.	330.0	264	10	-47
Int. Cabin Equip.	230.0	240	35	58

* Dimensions correspond to LEM coordinate system.

TABLE B-1 (CONT'D)

COMPONENT	WEIGHT	C. G. LOCATION X (INCHES)	Y (INCHES)	Z (INCHES)
ELECTRICAL POWER	(1431.0)			
Fuel Cells	228	229	0	-45
Oxygen & Tank	495	222	78	16
Oxygen & Tank (ECS)	223	218	72	-16
Hydrogen & Tank	255	224	45	0
RTG (4)	200	252	0	-80
Radiator	30	315	0	-49
COMMUNICATIONS	(19.5)			
T. V. Camera	11.5	240	35	58
Command Detector & Decorder	8.0	262	-12.5	62
TIEDOWN, LEVELING, UNLOADING	(227)			
Unloading	100	255	-90	0
Leveling	110	204	0	0
Tiedown	17	255	-90	0
NAVIGATION & GUIDANCE SUBSYSTEM	(28)			
Beacon transmitter	10	262	-12.5	62
Antenna	10	254	-50.0	32
Position Plotter	(8)	262	-12.5	62
TOTAL	(4564.9)			

* Dimensions correspond to LEM coordinate system.

TABLE B-2

COMPONENTS ADDED TO LEM DESCENT STAGE FOR CONVERSION TO LEM/S

COMPONENT	WEIGHT (LBS)	* C. G. COORDINATE		
		X (INCHES)	Y (INCHES)	Z (INCHES)
INSTRUMENTATION SUBSYSTEM	(480)			
LSSM Sci. Equip.	184	150	34	48
ESS	296	150	-54	-54
ELECTRIC POWER SUBSYSTEM				
Battery	76.9	140.0	32	-47.0
COMMUNICATIONS SUBSYSTEM				
T. V. Camera	11.5	309	-58	0
TOTAL	568.4			

* Dimensions correspond to LEM coordinate system.

TABLE B-3

COMPONENTS REMOVED FROM
LEM ASCENT STAGE FOR
CONVERSION TO LEM/S AND MOLEM

COMPONENTS	WEIGHT (Pounds)	* C. G. COORDINATES x Inches	y Inches	z Inches
Crew Provisions	(77.0)			
Thermal Coverall	7.5	242.0	-37.0	40.0
Lunar Boots	2.0	231.0	37.0	52.0
Meteoroid Protection Garment	30.0	236.0	-37.0	40.0
Supplementary Visors	.5	236.0	-37.0	40.0
Thermal Gloves	1.5	236.0	-37.0	40.0
PLSS Spare Parts	.5	236.0	37.0	40.0
** Restraints	35.0	258.2	0	37.8
Environmental Control System	(77.3)			
Water	68.0	302.0	0	0
GOX	9.3	282.3	0	-37.75
Electrical Power Subsystem	(291.8)			
LO_2 (Incl. 1.1 lbs. residuals)	22.2	282.3	0	-48.0
LO_2 Tank (1)	9.1	282.3	0	-48.0
LH_2 Tank (2)	45.0	270.25	0	-45.8
LH_2 (Incl. 4.2 lbs residuals)	18.1	270.25	0	-45.8
Fuel Cells	197.4	224.5	0	-42.5
Propulsion System	(5236.3)			
Fuel, tank and plumbing	1897.0	228.0	-71.26	0
Oxidizer, tank and plumbing	2973.0	228.0	44.54	0
Helium, tanks and plumbing	162.3	245.4	0	-49.3
Ascent Engine	204.0	224.0	0	0
Reaction Control Subsystem	(367.4)			
Propellant (Δ V)	312.4	282.0	0	0
Propellant (Attitude)	49.0	282.0	0	0
Ascent Tie-In Plumbing	6.0	282.0	0	0

*Dimensions correspond to LEM coordinate system.

TABLE B-3 (Continued)

COMPONENTS	WEIGHT	* C. G. COORDINATES		
		x Inches	y Inches	z Inches
Communications Subsystem	(27.0)			
Steerable Antenna (S-Band)	17.0	300.0	80.0	0
Lens-GFE	10.0			
Controls and Displays	(148.1)			
Stabilization and Control	70.3	277.0	0	73.0
Navigation and Guidance	43.8	277.0	0	73.0
Propulsion	10.0	269.0	-37.0	43.0
Reaction Control System	16.0	270.0	-37.0	43.0
Instrument Panels	8.0	270.0	-37.0	43.0
Total	6224.9			

* Dimensions correspond to LEM coordinate system.

** The restraints shown under Crew Provisions (weight 35 pounds) were removed for the LEM/S only. The total weight of items removed for MOLEM 6189.9.

TABLE B-4

COMPONENTS REMOVED FROM
LEM DESCENT STAGE FOR
CONVERSION TO LEM/S AND MOLEM

COMPONENT	WEIGHT (Pounds)	*C. G. COORDINATES x (Inches)	y (Inches)	z (Inches)
Environmental Control Subsystem	(236.5)			
Water	212.0	147.5	54.0	-43.25
Water Tank	23.0	147.5	54.0	-43.25
Plumbing - Water	1.5	147.5	54.0	-43.25
Electrical Power Subsystem	(307.8)			
LO_2 (Incl. 2.5 lbs residuals)	138.7	186	40.21	-41.62
LH_2 (Incl. 2.8 lbs residuals)	46.6	176	-48.97	-48.90
LO_2 Tank	31.4	186	40.21	-41.62
LH_2 Tank	79.2	176	-48.97	-48.90
LO_2 Plumbing	5.4	186	40.21	-41.62
LH_2 Plumbing	6.5	176	-48.97	-48.90
Communications Subsystem**	(25.8)			
Lunar Stay Antenna	13.2	140.0	32.0	-47.0
Erectable Antenna	12.6	140.0	32.0	-47.0
TOTAL	570.1			

* Dimensions correspond to LEM coordinate system

** Not removed from LEM descent stage for LEM/S conversion. Total weight removed for LEM/S is 544.3 pounds.

TABLE B-5

COMPONENTS ADDED TO LEM ASÇENT STAGE FOR CONVERSION TO MOLEM

COMPONENTS	WEIGHT (POUNDS)	*C. G. COORDINATES		
		x Inches	y Inches	z Inches
Structure Subsystem	(384.8)			
Chassis	300.0	210.5	0	24.0
Front Face Skin	33.1	250.0	0	70.0
Cabin Skin	22.7	250.0	0	50.0
Mid-Section Skin	29.0	250.0	0	0
Crew Provisions	(281.3)			
Space Suits	36.0	240.0	0	-12.0
Portable Life Support Sys.	52.5	236.0	37	40.0
Radiation Dosimeter	2.0	240.0	0	-12.0
Suit Mounted Comm. T.M.	1.0	240.0	0	-12.0
Bio-instrumentation	3.0	240.0	0	-12.0
Restraints (Hammocks)	10.0	298.0	0	18.0
Food, Packaging & Disinfect.	17.5	284.0	-20.0	- 3.0
Food, Packaging & Disinfect.	16.4	286.0	20.0	2.5
Food, Packaging & Disinfect.	51.8	289.0	0	46.0
LiOH-PLSS	46.1	240.0	0	13.0
Emergency Equipment	13.0	252.0	-37.0	38.0
Personal Hygiene	5.0	252.0	-37.0	38.0
Food Preparation Equip.	5.0	252.0	-37.0	38.0
Medical Equipment	5.0	240.0	0	13.0
Miscellaneous	17.0	252.0	-37.0	38.0
Environmental Control Subsystem	(430.6)			
LiOH - ECS	69.6	252.0	-37.0	38.0
Water+ 10 extra lbs tank wt.	209.0	302.0	0	0
Radiator (Incl. Condenser)	77.0	316.0	0	0
Storage Container Assy	75.0	252.0		
Instrumentation Subsystem	(819.3)			
Instrumentation Sensors	81.3	239.0	0	0
Scientific Instrumentation	738.0	214.0	0	0

* Dimensions correspond to LEM coordinate system

TABLE B-5 (Continued)

COMPONENTS	WEIGHT (POUNDS)	*C. G. COORDINATES x Inches	y Inches	z Inches
Electrical Power Subsystem	(1856.9)			
Fuel Cells	360.0	222.0	0	-44.0
Oxygen Tank No. 1	43.0	230.0	-41.0	0
Oxygen Tank No. 2	43.0	266.0	18.0	-46.0
Hydrogen Tank	223.0	240.0	50.0	- 6.0
Oxygen (Tank No. 1)	388.0	230.0	-41.0	0
Oxygen (Tank No. 2)	388.0	266.0	18.0	-46.0
Hydrogen	116.0	240.0	50.0	- 6.0
RTG (2 units)	100.0	233.0	0	-80.0
RTG (2 units)	100.0	268.0	0	-80.0
Electrical Control Assy.	15.9	268.0	0	-80.0
Radiator	80.0	316.0	0	0
Communication Subsystem	(61.2)			
TV Cameras (2)	23.0	300.0	20.0	90.0
Command Detector & Decoder	8.0	262.0	-12.5	62.0
Lunar Stay Antenna	13.2	300.0	40.0	-70.0
Erectable Antenna	17.0	308.0	60.0	0
Controls and Displays	(30.0)			
Navigation and Guidance	15.0	277.0	0	74.0
Locomotion	5.0	277.0	0	74.0
Inspection, Checkout & Malfunction	10.0	277.0	0	74.0
Mobility Subsystem	(1026.0)			
Wheels, Front (Folded)	336.0	233.0	0	0
Wheels, Rear (Folded)	300.0	287.0	0	0
Arms, Front Wheels	30.0	222.0	0	20.0
Arms, Rear Wheel	50.0	250.0	0	-20.0
Suspension - Front Wheels	150.0	210.5	0	0
Suspension - Rear Wheels	150.0	210.5	0	0
Ramp - Ingress, Egress	10.0	252.0	0	86.0
Unloading System	(500.0)			
Tracks	150.0	250.0	0	88.0
Turntable (Incl. Power Supply & Electronic Equip.)	350.0	203.0	0	46.0

TOTAL (5390.1)

* Dimensions correspond to LEM coordinate system.

TABLE B-6

COMPONENTS ADDED TO
LEM DESCENT STAGE FOR
CONVERSION TO MOLEM

COMPONENT	WEIGHT (Pounds)	* (Inches) C. G. COORDINATES		
		x	y	z
Electrical Power Subsystem Battery	76.9	140.0	32.0	47.0

* Dimensions correspond to LEM coordinate system

APPENDIX C

MOLEM PERFORMANCE CALCULATIONS

The results of the performance calculations for a 10,000 pound MOLEM during the mission traverse is shown in Figure C-1. and is also discussed in Section 9.14.3. The Maria Surface Model slopes, soil constants and the percent of distance traveled on each slope is shown in the first three columns. The resistance per wheel is next shown including steady state internal and external resistances and the tire resistance occurring during linear vehicle accelerations at .275 .55 and 1.1 feet per second per second.

The combined resistance per wheel is then tabulated wherein the internal and external steady state resistances are combined and also added to the varying acceleration phase resistances. The last 4 columns for resistance show the total vehicle resistance for the steady state and varying acceleration conditions.

The vehicle power requirements are now shown for the steady state and varying acceleration conditions. The steady-state velocities tabulated are 1.467, 2.93, 7.33 and 12.73 ft/sec corresponding to 1, 2, 5 and 8.7 mph. The power available for mobility is 7.0 kilowatts and this limiting value is used to establish the steady state velocities capability vs lunar slopes. Similarly the power requirements and final velocity capabilities are shown for the acceleration rates of .275, .55 and 1.1 feet per second per second. The time required and distance traveled to achieve the velocities shown is tabulated at the bottom of the Table. Finally the drawbar pull to weight ratios are tabulated for the varying lunar slope conditions.

MARIA SURFACE MODEL (KSC-TR-83-D ELMS)			RESISTANCE / WHEEL (POUNDS)				
SLOPE DEGREE	SOIL* CONSTRAINT	PERCENT DISTANCE TRAVEL	INTERNAL R_L	EXTERNAL R_e	ACCELERATION FT/SEC² $a=.275$	$a=.55$	$a=1.1$
0	$K_\phi=.5$	11.0	6.25	48.1	25.6	51.25	102.5
1	$n=.5$	22.5		55.1			
2		24.5		62.4			
3		16.0		68.6			
4		10.0		77.0			
5	$K_\phi=1.0$	7.5		46.1			
7.5	$n=.75$	3.0		64.2			
10		3.0		74.3			
15	$K_\phi=3.0$	1.5		110.4			
20	$n=1.0$	.5		145.0			
25	$K_\phi=6.0$ $n=1.25$	.3		177.6			
30	HARD SURFACE	.2	6.25	208.3	25.6	51.25	102.5

TIME REQUIRED TO REACH VELOCITY SH

DISTANCE TRAVELED TO REACH VELOC

* FOR ALL SLOPES LISTED:
$C=0$, $K_c=0$ $\phi=32°$

MC

COMBINED RESISTANCE/WHEEL (POUNDS)				TOTAL VEHICLE RESIST (POUNDS)		
STEADY STATE	ACCELERATION FT/SEC²			STEADY STATE	ACCELERATION F	
	a = .275	a = .55	a = 1.1		a = .275	a = .55
54.4	80.0	105.6	156.9	217.6	320.0	422.4
61.4	87.0	112.6	163.9	245.6	348.0	450.4
68.6	94.2	119.8	174.1	274.4	376.8	479.2
74.8	100.4	126.0	177.3	299.2	401.6	504.0
83.2	108.8	134.4	185.7	332.8	435.2	537.6
52.3	77.9	103.6	154.8	209.2	311.6	414.4
70.5	96.1	121.8	173.0	282.0	384.4	487.2
80.5	106.1	131.8	183.0	322.0	424.4	527.2
116.6	142.2	167.8	219.1	466.4	568.8	671.2
151.2	176.8	202.4	253.7	604.8	707.2	809.6
183.8	209.4	235.1	286.3	735.2	837.6	940.4
214.5	240.1	265.8	317.0	858.0	960.4	1063.2

IOWN AT INDICATED ACCELERATION RATE- S

ITY SHOWN AT INDICATED ACCELERATION

TABLE C-1

)LEM PERFORMANCE SUMM

ANCE	VEHICLE POWER					
	STEADY STATE PHASE				ACCELERATION RA	
T/SEC²	VEHICLE VELOCITY - FT/SEC				FINAL VELOCITY	
a = 1.1	v = 1.467	v = 2.93	v = 7.33	v = 12.73	v = 1.467	v = 2.93
627.6	.721	1.44	3.60	6.26	1.06	2.12
655.6	.814	1.63	4.07	7.07	1.15	2.30
684.4	.910	1.82	4.54	7.89	1.25	2.50
709.2	.992	1.98	4.96	8.67	1.33	2.66
742.8	1.10	2.20	5.51	9.58	1.44	2.88
619.2	.693	1.39	3.46	6.02	1.05	2.06
692.0	.935	1.87	4.67	8.11	1.27	2.54
732.0	1.07	2.13	5.33	9.26	1.41	2.81
876.4	1.55	3.09	7.73	13.4	1.88	3.77
1014.8	2.00	4.00	10.0	17.4	2.34	4.68
1145.2	2.44	4.87	12.2	21.2	2.78	5.55
1268.0	2.84	4.68	14.2	24.7	3.18	6.36
SECONDS					5.3	10.6
-FEET					3.9	15.6

MARY

REQUIREMENT - KW

ATE = .28 FT/SEC²		ACCELERATION RATE = .55 FT/SEC²				ACCELER
- FT/SEC		FINAL VELOCITY - FT/SEC				FINAL V
v = 7.33	v = 12.73	v = 1.467	v = 2.93	v = 7.33	v = 12.73	v = 1.467
5.30	9.21	1.40	2.80	7.00	12.2	2.08
5.76	10.0	1.49	2.98	7.46	13.0	2.17
6.24	10.8	1.59	3.17	7.94	13.8	2.27
6.65	11.6	1.67	3.34	8.35	14.5	2.35
7.21	12.5	1.78	3.56	8.91	15.5	2.46
5.16	9.0	1.37	2.74	6.86	11.9	2.05
6.37	11.1	1.62	3.23	8.07	14.0	2.29
7.03	12.2	1.75	3.49	8.73	15.2	2.43
9.42	16.4	2.22	4.44	11.1	19.3	2.90
11.7	20.3	2.68	5.36	13.4	23.3	3.36
13.9	24.1	3.12	6.23	15.6	27.1	3.81
15.9	27.6	3.52	7.04	17.6	30.6	4.21
26.6	46.3	2.7	5.3	13.3	23.1	1.3
97.5	294.1	2.0	7.8	48.8	147.3	1.0

			DRAWBAR PULL TO WEIGHT RATIO
ATION RATE = 1.1 FT/SEC^2			
VELOCITY - FT /SEC			
N= 2.93	N= 7.33	N= 12.73	DP/W
4.16	10.4	18.1	.494
4.34	10.9	18.9	.478
4.53	11.3	19.7	.460
4.70	11.7	20.4	.445
4.92	12.3	21.4	.425
4.10	10.3	17.8	.500
4.58	11.5	19.9	.456
4.85	12.1	21.1	.432
5.80	14.5	25.2	.345
6.72	16.8	29.2	.262
7.58	19.0	33.0	.184
8.40	21.0	36.5	.110
2.7	6.7	11.6	
3.9	24.4	73.6	

DISTRIBUTION

INTERNAL

DIR
DEP-T
R-DIR
R-AERO-DIR
-S
-SP (23)
R-ASTR-DIR
-A (13)
R-P&VE-DIR
-A
-AB (15)
-AL (5)
R-RP-DIR
-J (5)
R-FP-DIR
R-FP (2)
R-QUAL-DIR
-J (3)
R-COMP-DIR
-RSP
R-ME-DIR
-X
R-TEST-DIR
-I
I-DIR
MS-IP
MS-IL (8)

EXTERNAL

NASA Headquarters
MTF Col. T. Evans
MTF Maj. E. Andrews (2)
MTF Capt. Bart Cambell
MTF Mr. D. Beattie
R-1 Dr. James B. Edson
MTF William Taylor

Kennedy Space Center
K-DF Mr. von Tiesenhausen

EXTERNAL

Northrop Space Laboratories
Huntsville Department
Space Systems Section (5)

Scientific and Technical Information Facility
P. O. Box 5700
Bethesda, Maryland
Attn: NASA Representative (S-AK/RKT) (2)

Manned Spacecraft Center
Houston, Texas
Mr. Gillespi, MTG
John M. Eggleston
C. Corington, ET-23 (1)
William E. Stoney, ET (2)

Donald Elston
Manned Lunar Exploration Investigation
Astrogeological Branch
USGS
Flagstaff, Arizona

Langley Research Center
Hampton, Virginia
Mr. R. S. Osborn